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MANUAL OF LITHOLOGY:

TREATING OF

THE PRINCIPLES OF THE SCIENCE

WITH SPECIAL REFERENCE TO

MEGASCOPIC ANALYSIS.

BY

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WITH SIX PLATES.

SECOND EDITION.
FIRST THOUSAND.

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PREFACE TO THE SECOND EDITION.

THE microscope has forced lithology and petrography so widely apart that the layman is often at a loss to recognize old acquaintances under new names. This edition of lithology is written on the same basis as the last — for the beginner in the subject who wishes a thorough knowledge in the megascopic presentation of the subject, in a fuller and more compact arrangement than can be obtained in geological text-books. It is also designed for the engineer who wishes to understand the valuation of rocks for economic purposes. The arrangement is such that those who wish to continue the work in the microscopic analysis of rock-forming minerals, as taught in petrography, will have nothing to unlearn. The reader is supposed to have a practical acquaintance with megascopic crystallography and mineralogy, the use of the blowpipe, and the ordinary methods of chemical analysis, so that these subjects are merely touched upon in the description of the more common megascopic rock-forming minerals. An addition has been made in the line of the economic value of rocks, and the body of the book has been entirely rewritten, and is from five to six times the size of the former edition, so rapidly has the subject grown. Credit has been given for data taken from other authorities.

E. H. W., JR.

LEHIGH UNIVERSITY, July 22, 1895.

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DESCRIPTION OF THE PLATES.

The cuts of Plates I, II, and 1 to 4 of VI are 5/6 natural scale; 5 and 6 of IV are 3/4 the same; and 6 of V is 1/20 the same; the rest are of natural scale.

PLATE I.

1. Medium-crystalline-granular (granitoid) porphyritic granite.
2. Pudding-granite with concretions of predominant mica.
3. Granitoid olivine-diabase.
4. Fine-crystalline-granular diabase.
5. Similar leucite-tephrite, with phenocrysts of leucite.
6. Fine-crystalline-granular and porphyritic dacite.

PLATE II.

1. Porphyritic hornblende-granitite.
2. Luxullionite.
3. Coarse-granular elæolite-syenite.
4. Porphyritic dolorite.
5. Oligoclase-porphyrite.
6. Orthoclase-porphyry.

PLATE III.

1. Orbicular diorite.
2. Pegmatite.
3. Fine-crystalline hypersthene-andesite (vesicular).
4. Microcrystalline rhyolite (vesicular and porous).
5. Microcrystalline limburgite (amygdaloidal).
6. Microcrystalline quartz-porphyry (vesicular porous pyroclastic breccia).

PLATE IV.

1. Perlite (perlitic).
2. Obsidian (vitreous).
3. Tachylite (scoriaceous).
4. Olivine-rock (volcanic bomb).
5. Halleflinta (fluidal).
6. "Bastkohl" (fibrous).

PLATE V.

1. Limestone (oölitic).
2. Quartz-conglomerate (pudding-stone).
3. Brecciola.
4. Rolled sand (river).
5. Sharp sand (glacial rock-meal).
6. Till (crushed slate with angular débris and rolled sand, gravel, etc.).

PLATE VI.

1. Clay-slate (slaty cleavage from pressure).
2. Calcareous mica-schist (flat-parallel).
3. Calcareous mica-schist (lenticular-parallel).
4. Hornblende-schist (irregular).
5. Gneiss (foliation).
6. Gneiss (segregation in strings).

MANUAL OF LITHOLOGY.

INTRODUCTION.

THE tendency of modern rock analysis is toward a simplification of the subject, and the discarding of useless and misleading divisions and names. At present there seems to be a reaction against separating dike-forms of rocks from their massive states, the attempting to distinguish rocks on account of geological age, and the basing a rock name on a chemical bulk analysis. The tendency in metamorphism is backward to the old theories of primary origin, and "eruptive" gneiss is no longer a misnomer to many. It seems necessary to faintly outline the present state of belief of petrographers on some of the above subjects, so that the reason for the arrangement chosen in this book can be understood, and the first subject will be in regard to dike-rocks. This state is produced whenever an eruptive is forced into or through a fissure whose walls are approximately parallel to one another. Depending on the depth of the fissure below the surface, its walls will be of varying temperatures, and the fluid mass will be cooled correspondingly rapidly or slowly; but, whether slowly or rapidly, the bulk of the intruded mass will be slight when taken transverse to the cooling surfaces, and the crystallization, at best, will not reach the development that obtains in larger masses that cool more slowly; so that dike-cooling

will give smaller sized grains. If the cooling is slow and the walls heated, there may be a uniformity of grain across the fissure; but the fact that the mass has been cooled before becoming stagnant at the point of consolidation will only allow a uniformly small grain to form. This even grain has been taken as a dike-facies when it depends on the heating of the dike-walls to a degree corresponding to the temperature of the intruded mass; and that is caused by the fissure being deep-seated enough to be within the heated abysses, or by so long a passage of the hot magma through the fissure that the country-rock has been heated to a great distance. This presupposes an escape of the magma at the surface readily during the first part of the flow; or the influence of the walls would have cooled the mass and plugged the fissure. We need, therefore, a hot liquid lava and a free escape at the surface for the first portions of a flow resulting in a final stagnation that crystallizes evenly across the dike. It is seen at once that all dike-flows cannot follow this sequence, owing to narrowness of fissure or coolness of lava; so that only *some* dikes have this facies. We find a similar facies along the peripheries of bosses and large laccoliths; so that it is not due to the shape of the cooling magma, but to the rapidity of cooling.

A late eminent authority objected to claiming so great a metamorphic power for dikes, and especially for dike-granite. He stated that the great effect of metamorphism shown in the country of the dike-walls was not due to the granite (which was probably a trachyte when intruded), but to a subsequent regional metamorphism that affected both dike and walls, altering the former to granite, and the latter to its present condition. It would be sufficient to quote the words of Dr. Barrois that regional metamorphism and contact metamorphism are much the same thing; but in this case there is a misapprehension that will extend to others

and create a wrong impression. In answer it may be said that it is more probable to imagine the extent of the metamorphism due not to the fact that the granite is in the dike form, but to the fact that dike-walls are sometimes heated, as above described; that this heating from passing hot fluid produces the metamorphism, and the stagnant fluid crystallizes uniformly and sharply up to the dike-walls. Against the argument of a metamorphosed trachyte may be advanced the statement that the latter supposition would not account for the sharpness of the dike-walls, as regional metamorphism of a nature that would produce the necessary mineral zones in the aureola would more or less obliterate the walls, or cause a shading from the granite facies to that of the metamorphosed walls, and such changes are not found. It may also be advanced that it does not require a greater amount of heat to metamorphose the walls in the one case than in the other, and that it is as easy to suppose the walls heated before the stoppage of the flow, either by the length of time during which the flow passed, or from the fact that the whole region was heated to a point just below metamorphism (by orogenic or other causes) before the fracture and intrusion took place, and that the intrusive supplied the needed increment for metamorphism. It is also difficult to see how regional metamorphism would produce an aureola and zones about a cold dike of trachytic habit, and not extend generally through the mass.

The attempt to separate dike-rocks from those filling plugs is still more hard to understand, as both begin and end alike, differ only in shape, and contain similar fillings. Dike-rocks are generally accepted as fillings of fissures which may have reached the surface and through which extrusives passed. Lapse of time has allowed those surface states to be denuded, and we have only the filled vent.

The credit of destroying the idea that rocks can be separated according to geological age belongs in a high degree to American geologists. If we take the mixture of mica, quartz, and feldspar which forms the rhyolite-granite series, we are asked to believe that the quartz-porphyries are the extrusives of the granite in the past, and the rhyolites in the present. We find quartz-porphyries as late as the Eocene (in Elba); and the late G. H. Williams found in the Archæan area of the South Mountain along the border-line of Pennsylvania and Maryland pre-Cambrian rhyolites devitrified and altered, but retaining lithophysæ and flow structure. These two examples, which demolish the hypothesis in this group, are parallelled in other groups, so that the American and English authorities do not allow groupings according to fancied geological ages.

Bulk analyses of rocks are given in the books on the subject, and rock groups created from chemical differences. The researches of Lang conclusively show that nothing can be thus based, as the same rock will show a varying bulk analysis when fresh and weathered, and the same mineral group will vary widely in the components of a bulk analysis; while rocks of varying mineral composition will agree closely in bulk analyses. The rock groups of the future must, therefore, depend more on mineral than chemical composition. While the majority of authorities define an "acid" rock as one whose bulk analysis shows a certain percentage of silica, Lessing says that it is one that carries a surplus of silica after saturating the bases, no matter how great or small that may be. The terms "acid" and "basic" are indefinite terms, and bulk analyses are misleading.

Sorby's theory of differentiation of magmas is rapidly pushing its way to the front as a new basis for dividing rocks, though how that is to be done is not yet sufficiently plain. The theory as modified by Iddings is finding quite

general acceptance, and the work of the future may be devoted to the study of Judd's "petrographic provinces." It is possible that differentiation will finally take the subject out of the hands of the average student, and that it will be understood only by the expert with a microscope. It is a matter of congratulation that the familiar rock names have been left in the majority of cases, so that there is little to be unlearned as the science progresses. In general it may be said that modern progress has been towards simplicity of arrangement.

In the following pages many rocks based entirely on microscopic distinctions have been given for the purpose of making this a complete book; but in every case there is a distinction between what can be seen by the eye (with a lens) and by the microscope. The symbol (*M*) will be used for whatever can be seen by the eye, and will be equivalent to "megascopic," "by the eye," etc., while the lower-case (*m*) will be equivalent to "microscopic," "by the microscope," etc. In rock definitions these symbols will be freely used, as well as in the discussion of states and varieties of rocks and forms of minerals.

PRELIMINARY DESCRIPTION.

Geology is the discussion of the history of the earth, and of its life, from the earliest times. **Geognosy,** or *structural geology*, is that branch which deals with the components of the earth, their arrangement to form its structure, and the development of the latter. The materials can be separated into the *envelope* (air and water) and the *lithosphere.* It is with the latter, principally, that structural geology has to do, and this solid portion can be considered in two ways: (1) as formed of individual *rocks;* (2) as arranged in masses or beds to form *terranes* (as used by J. D. Dana; *terrain* of C. D'Orbigny). **Lithology** is that division of geognosy which treats of the rocks of the lithosphere as mineral aggregates, under all conditions of hardness, and all states of aggregation and consolidation. Aggregates totally lacking consolidation are included; so that loose bodies (as sand, clay), viscoids (as asphalt, ice), organic bodies (as peat, guano), hard bodies (as granite, trap)—all are rocks. According to Lang, a *rock* is an individual product of an uninterrupted rock-forming process. An eruptive rock is formed at a single earth-throe; a secondary rock is formed from an eruptive by an uninterrupted action of natural forces. To fully understand rock origin it will be necessary to include some definitions of terrane structure, as well as some theories of the constitution of the earth's interior. In distinction to lithology, there is a second method of studying rocks by the microscope. This is more of a mineral analysis than lithology, and bears to it exactly the same relation that chemical analysis and blow-

pipe reactions do. It investigates the origin of the rock as well as its composition, and is, therefore, a higher branch of the subject, called **petrography.**

Rocks are mineral aggregates, and may be *simple*, when formed necessarily of one mineral, or *composite*, when made up of two or more different ones. Rock definitions should contain only the necessary and essential components, and all accessory minerals should be placed in the following discussion. *Necessary* ingredients give the name to rock classes: "A granite is composed of quartz and feldspar." *Essential* ingredients mark rock species; as the addition of hornblende to the above makes *hornblende* granite; the addition of augite, *augite*-granite. *Accessory* ingredients are local in their occurrence, or inconsiderable in amount; but, when more than usually abundant, may form rock subspecies; as the presence of considerable hypersthene in augite granite makes *hypersthene*-augite-granite; or an abundance of garnets in mica-schist makes *garnetiferous* mica-schist. Necessary and essential ingredients may be further defined by saying that a change in the former would throw the rock into another class, and in the latter into another species. A rock may have the same mineral as necessary and accessory, or as essential and accessory; as *quartz*-schist must necessarily have quartz; but veins of quartz traversing such a schist are but the filling of a fracture that may run into adjoining rocks of a different composition, and are, therefore, only in the slightest degree accessory. In the resolution of pyroclasts, or a partly solidified magma at depths in the earth, there may be mineral components more resisting than the bulk of the mass, and these will float in the magma and be etched (corroded) by it; or in the case of an intratelluric crystallization before differentiation, or the eruption of magmas of different composition through the same vent and at the same time, there may be a similar

placing of the intratelluric phenocrysts in a bath differing from the one in which they formed, and a similar etching will result. M-Lévy and Fouqué apply the term *allogenic* to all crystals formed at such different periods as would cover the first supposition; but the term will not apply to those similar ones formed through corrosion in a differentiated portion of the same mass. Minerals may also be classed as *primary* and *secondary*. The former are crystallizations from the original magma before solidification; the latter, due to causes acting after solidification. These causes may be:

(*a*) Growths about the original grains or crystals, by which felsites have been devitrified and changed to quartz-porphyries; sandstones have been altered to quartzites, as at Bethlehem, Pa.,—in this case the growths are of the same mineral material.

(*b*) Growths of different mineral matter about crystals to form *paramorphs*.

(*c*) Infiltrations from the country-rock, or from the interior of the rock itself, which crystallize in the openings of the rock (vesicles, pores, cavities, fissures, cracks, joint planes, etc.) to form amygdaloids, druses, geodes, nests, strings, etc., as agate, zeolites.

(*d*) Replacements of mineral matter without changing the form of the original mineral, as *pseudomorphs*, as in the pyritiferous porphyry of Leadville, where pyrite forms pseudomorphs after hornblende and biotite.

The following definitions and classifications are based on work with the unaided eye (megascopic analysis), though an appeal to the microscope will be taken in the discussion of the theories of rock-formation; but before entering upon them it is necessary to touch upon that branch of lithology which treats of the individual components of rocks, *mineralogy*, as far as the description of the species common to rocks, and called *rock-formers*, and the manner in which they occur

in rocks. The student in mineralogy pays attention to the crystallographic, optical, physical, and chemical characters of the mineral as an individual, crystallizing with freedom, and uninfluenced by association with others in process of formation. If exceptions occur, they are noted as foreign to the usual habit. Mineralogy from a lithological standpoint is another study, as all of the minerals which are rock-formers must of necessity mutually influence one another; so that the first thing to be noted is the shape in which the mineral will be found in rock masses. The next thing of importance is a method of isolating mineral species for inspection or analysis. The only method of inspection here treated is by the pocket lens. The blowpipe and chemical tests are the same as in mineralogy. It is well to note that the rapidity of response to the latter depends on the ratio of the extent of surface exposed to the volume of the mineral. This increases with the extent of comminution; so that powdered forms are most quickly acted upon by solvents. In crushing specimens for chemical tests the powder should be fine enough to ensure definite and rapid reaction; for physical tests the product must retain as sharp an outline and as great freedom from dust as possible. A rough crushing through rolls frequently separates the component minerals in grains of various sizes, and these can be separated by classification through screens. Woven wire can be procured with a mesh of 1–.2 mm., and bolting-cloth of various grades to still finer sizes. Screens need not exceed $2\frac{1}{2}$–3 inches in diameter. A tinsmith can make a series of screen-frames for a field outfit that can be readily renewed at any time, though the wear is insignificant. Make a template by turning one end of a piece of oak two inches square and six inches long to form a cylinder two inches in diameter, and a scant half inch long, and have the tinsmith solder half-inch wide strips of light tin so as to exactly fit the cylinder. Make the same

number of small cylinders, of the same length and $\frac{1}{8}$–$\frac{1}{16}$ inch greater diameter. Place a smaller ring on the template, and cut from the screen material a circle four inches in diameter. If it be of bolting-cloth, lay it centrally over the ring, and slip over cloth and ring one of the larger rings, and drive down with a few taps of a light hammer. The cloth will be stretched and retained between the two rings, and when worn out can be replaced by a new piece. In the case of the wire cloth the edges must first be bent over the template with the fingers, and then placed as above described. This series of screens can be arranged from coarse to fine above one another by procuring tin cylindroids (slightly conical) two inches long, with the larger end fitted to the outside of the screens, and the smaller end to the inside of the same. Any number of screens can thus be arranged in a set, and the ends of the top and bottom ones closed by caps, so that no dust will escape on shaking a mixture placed in the upper and larger screen. On separating the screens each will hold the next larger class, and these may be sorted in any one of the many varieties of laboratory sorters with ascending currents. The most common way is to use a solution of some salt which gives a definite and high specific gravity. The requirements of such a solution are that it shall be as harmless as possible; that it shall be stable under ordinary conditions of temperature; that it shall have no effect on the minerals separated; that they, in turn, shall not react upon it; that diluting it will not alter its composition; and that evaporation will bring it back to its condition before dilution. D. Klein, in 1881, proposed a solution that now bears his name, which fulfils the above conditions, and can be diluted with water. There are other solutions of different sp. grs.; but they require some other diluent, are less stable, or are noxious. *Klein's solution* is formed by dissolving a very

soluble borotungstate of cadmium in slightly less than ten per cent. of its weight of water at 22° C. At 15° C. it has a sp. gr. of 3.28; but by evaporating over a water bath till olivine floats in the warm solution it has, on cooling, a sp. gr. of 3.6. By adding water the gravity can be reduced to any required figure, and evaporating will restore it again. In using this or any other solution that can be changed by dilution, and when a certain sp. gr. is to be obtained, we place on the surface a considerable fragment of a mineral with density slightly greater than that desired, and dilute by single drops till the mineral sinks. It must be kept in mind that a number of circumstances may affect the result, and that the sorts may not be exactly what we think them to be, as (1) the buoyant effect of a liquid increases quite rapidly with fineness of crushing, as is well known in ore-dressing; (2) the buoyant effect is greater in highly cleavable minerals (micas) than in others of the same density that break in other forms; (3) minerals frequently hold other minerals as inclusions; (4) the fragments may be mixtures of widely varying minerals, so arranged as to have a medium density; (5) incipient weathering, metachemism, etc., may have set in. Minerals with magnetic properties can be removed from the rock powder by a magnet (magnetite, pyrrhotite, etc.).

The value of *chemical analyses* depends on how they are made—whether "bulk analyses," where the sum of the elements or their oxides for the whole rock is obtained; or each mineral is isolated as far as possible and its composition learned. It has been long known that there was too much variation in the silica and other ingredients of rocks,—granite, for example,—to allow a "type analysis" to be adopted, and lately the majority of authorities have abandoned the attempt to reconstruct the mineral character of a rock from

its chemical bulk analysis, as many rocks of greatly varying mineral composition have nearly the same bulk analysis. Iddings is quoted as saying that the variations in the rapidity of cooling the fluid mass cause the variations in mineral composition, independent of the pressure exerted. Bulk analyses, therefore, should be used with caution, and as checks, or for purposes of comparison; as a fresh and weathered fragment of the same rock, and taken from places adjacent to one another, will give greatly varying bulk analyses, and might throw the specimens into different species were they to be taken alone.

The examination of mineral powder of varying coarseness can best be made on paper, using a color strongly contrasting with that of the powder—unless specimens of it are to be preserved, and those can be mounted on glass slides with Canada balsam. Microchemical tests can be made in the field with a good lens and glass slides, and, following the suggestion of Bolton, a bottle of finely powdered citric acid should be carried for acid tests (carbonic acid), which can be applied to the streak of the rock, or its powder placed on glass and both wet. A solution of rock powder in acid will leave behind all insoluble residue, which can be examined by the lens. The two oxides of iron can be detected in a similar way by the use of HCl and cyanide salts of potash. This list can be further extended; but it is sufficient to say that the expert in qualitative analysis can devise similar tests on slides that will give under the lens a good idea of the composition of the rock in case it be non-crystalline or compact. Bořicky suggests the action of pure hydrofluosilicic acid on silicates in minute fragments, as follows: fix a minute particle on a glass plate with balsam and moisten with a drop of acid; place under a bell glass near a vessel with water and stand for twenty-four hours; then dry by placing over calcium chloride, and examine with a lens, when fluosilicate

of potassium will show as cubes; of sodium as hexagonal prisms. Nèpheline compounds when powdered and touched with HCl will, on drying, show chloride of sodium crystals. Klemert and Renard's work on microchemistry (Brussels, 1886) covers the subject fully. It is needless to add that the blowpipe set should always be on hand for mineral analysis.

In studying the shape of an "aureola" of contact metamorphism in the field, it may be well to bear in mind that heat transmission in slate and ordinary shales is four times as rapid with the bedding planes as across them. We can find the values of heat transmission in any rock in the laboratory by covering with wax one side of moderately thin sections, made at various angles with the bedding-planes, or along sections where the rock seems to show variations in structure or density, and drilling through the middle of each a hole of sufficient size to pass a platinum wire, which will be heated by an electric current. The heat will be transmitted more rapidly in a thin than a thick section with a given size of wire, and the relative rates of transmsision will be marked by the shape of the melting wax. If the platinum wire be no longer than the thickness of the section, there will be no heating of the wax by radiation. The record can be kept by photographing the specimen, or dusting upon the melted wax a powder of a different color. A series made at varying angles will give the heat values for that rock, and their comparison with similar ones of the same species from another locality may show differences due to moisture, density, etc., as heat travels faster in wet than in dry rocks: in dense than in loose.

ROCK-FORMING MINERALS.

Minerals can be divided into two classes: those which are the most abundant, and those which are the most common. The most abundant minerals are generally grouped in a few species; the most common minerals may never be visible to the eye in the majority of cases; may exist always in a minute proportion, and yet be always present. Under the modern theory of crystallization from a perfectly fluid magma in the hot abysses of the earth's crust it is decided that the most basic combinations are first to form, so that they are frequently included within those forming later. If we take into consideration the minerals of common occurrence, as far as that term stands for generality of occurrence, we shall find that our list contains species not readily seen with the eye or lens, as magnetite, titanite, specular hematite, apatite, allanite, zircon, and olivine. These are among the first to form in the fluid magmas. If we arrange the minerals in the order of their prominence as rock-formers, we shall find that the (*M*) species of common occurrence are quartz, feldspars, micas, amphiboles, pyroxenes, calcite, and dolomite; those of frequent occurrence, nepheline, leucite, melilite, sodalite, haüyne, olivine, chlorite, talc, serpentine, hydromicas, garnet, apatite, epidote, magnetite, ilmenite, zircon, and tourmaline; those occurring as rocks of large extent, by themselves, calcite, dolomite, magnesite, cryolite, asphalt, coal, iron ores, salt, bauxite, sulphur, and a few sulphides.

1. Quartz. Rhombohedral. It occurs (1) phenocrystalline:

(*a*) As an independent rock in veins, beds, and masses of primary or metamorphic origin;

(*b*) As a necessary component in many primary rocks, and especially in the metamorphic schists, e.g., granite, gneiss.;

(*c*) As an essential element in many rocks to form species of an otherwise quartzless class, as quartz-basalt, quartz-diorite; and

(*d*) As principal ingredient in many clastic rocks (sandstones, conglomerates), and as sand and gravel.

It occurs (2) cryptocrystalline and amorphous:

(*a*) As agate, which is a variegated combination of alternate layers of common quartz (amethyst, or chalcedony) with jasper, carnelian, etc., formed usually in the amygdaloidal cavities of eruptive rocks, as geodes, or in metallic veins. The extensive establishment for manufacturing articles from agate at Oberstein long since exhausted the local deposit, and for many years the supply has come from the volcanic rocks of Uruguay. Agate is also found in the similar rocks of Iceland, the Faroe Islands, and (from the decomposition of the rocks) in the sands of Lake Superior and the northern part of the Mississippi River. Moss agates are not banded.

(*b*) As jasper (bright red), flint (grayish blue to black from carbon), and chert, or hornstone (gray, yellow, green, red, brown, black). Jasper is generally associated with iron ores, as it obtains its color from anhydrous sesquioxide of iron, and can be traced by regular gradations from a slightly ferrated cryptocrystalline form of quartz to a slightly siliceous hematite, as the ferric solutions have more and more replaced silica by metachemism. It occurs under the same conditions as hornstone, as concretions and layers in rocks. Flint occurs as concretions in calcareous sediments, which, in some cases, have been formed from the spiculæ of sili-

ceous sponges. The principal locations are the Chalk of northern Europe, and the Upper Jurassic of Bavaria. Hornstone is not so tough as flint, and breaks with a more splintery fracture. It is abundant in the Siluro-Cambrian limestone of the eastern part of Pennsylvania, and is the form of quartz frequently met with in petrified wood. Basanite is a black jasper.

H. 7; Gr. 2.5–2.8, average 2.6. Colorless and limpid, or variously colored. Comp. SiO_2. Luster vitreous, sometimes resinous or waxy, especially on the surface of fractures.

Bp. Crystalline variety: alone, unaltered; with soda dissolves with effervescence; untouched by microcosmic salt; cryptocrystalline variety: with borax dissolves to a clear glass. Chem. Crystalline: soluble in HF alone; cryptocrystalline: slightly acted upon by caustic alkali.

Weathering. Crystalline: unchanged, though crystals have been found with corroded edges; cryptocrystalline: forms a white crust, as in flints.

Associated with almost every other mineral except eucite, nepheline, and melilite; but it is more commonly found with orthoclase and the acid silicates. It frequently occurs with tourmaline, rutile, cassiterite, and topaz. It is found more frequently with hornblende than pyroxene, with muscovite than biotite, and seldom with olivine.

2. **Tridymite.** Hexagonal. Tabular crystals, grains. H. 7; Gr. 2.28–2.33. Colorless. Luster of fracture, vitreous; of face, pearly. Fracture conchoidal. Comp. SiO_2.

Bp. Infusible; with soda fuses with effervescence to a colorless glass. Chem. Pure silica, soluble in a boiling solution of sodium carbonate.

Weathering. Gradually changes from colorless to white.

Tridymite occurs generally in acid extrusive rocks in thin minute glassy hexagonal crystals. It has been found in the massive states of these rocks and in volcanic ash; also

as enclosures in opal and quartz. It is a frequent component of rhyolites, andesites, and trachytes.

3. Opal. Massive, amorphous.

H. 5.5–6.5; Gr. 1.9–2.3. Variously colored, colorless, or characterized by a rich play of colors that is termed "opalescent." Transparent to opaque. Luster usually waxy or greasy; sometimes resinous and vitreous.

Bp. Most varieties decrepitate on heating, and yield water in the matrass; infusible; become opaque, except the yellowish varieties, which contain hydrated sesquioxide of iron and turn red; there is no change of color. Chem. Amorphous silica combined with non-essential water, which may vary from 2–20 per cent, but usually varies from 3–9, and a small amount of coloring matter. It differs from quartz in being soluble in a solution of caustic potash, from which it can be precipitated by sufficient ammonium chloride, and in being more soluble in heated alkaline waters.

Weathering. Forms a colorless crust on the earthy and porous solid forms which are colored. Is dissolved by alkaline waters and disappears when in the form of ooze.

Opal occurs (1) as metachemic exfiltrations in eruptive rocks, (*a*), as precious opal, which fills vesicular cavities or clefts in trachytic rocks, as in Hungary and Mexico, and sometimes in basalt; (*b*), as hyalite, a transparent and colorless form which is found under similar conditions in basaltic rocks, and with a globular, reniform, botryoidal, or stalactitic structure.

It occurs (2) in metamorphic rocks, as in some slates and crystalline rocks. The "Guinea quartz" of the rocks associated with the iron ores of central Virginia is said to be opal.

It occurs (3) in petrifactions where the cellulose of wood has been replaced by this soluble silica.

It occurs (4) from the decomposition of siliceous minerals of volcanic rocks to form fiorite, which is similar to hyalite.

It occurs (5) in concretionary deposits about the Iceland and Yellowstone geysers under the name of geyserite. This is soft when first formed, but hardens on exposure; color white or grayish; stalactitic, massive (compact and scaly), usually opaque, sometimes crumbly on drying.

It occurs (6) in organic aggregates, as the skeletons of hexactinellid sponges; the shells of radiolarians and diatoms, to form tripoli or randanite and through the agency of confervid algæ to form geyserite.

THE FELDSPARS.

After quartz this series is the most important of rock-formers, and especially in eruptives, of which the larger proportion is a feldspar. Crystallographically it is divided into two groups, the *monoclinic*, or (from the principal type) the *orthoclases*, and *triclinic*, which is further divided into the *anorthoclases* and the *plagioclases*.

In the orthoclases the angle measured over the two most perfect cleavage planes is 90°; in the anorthoclases it is slightly, and in the plagioclases considerably, less than that angle. All feldspars tend to form twins, and in some cases the duplication is marked.

THE ORTHOCLASES.

These are orthoclase and sanidine. The former occurs usually in the rocks of the Archæan and in the intrusives, the latter in the extrusives. Orthoclase even when fresh never has the glassy habit of sanidine, and approaches it most nearly in orthophyric porphyries.

4. Orthoclase (Potash Feldspar). Monoclinic.

H. 6; G. 2.5–2.56. Transparent-translucent. Colorless, more frequently greenish white or flesh-red. Luster vitreous, sometimes pearly on cleavages. Comp. $KAlSi_3O_8$.

Bp. Fus. 5 on thin edges to a dull porous glass; with microcosmic salt, soluble with difficulty, leaving a skeleton of silica; with cobalt, fused edges are colored blue. Chem. Untouched by acids, except HF, which completely decomposes it; decomposed by fusion with alkaline carbonates.

Weathering. Decomposes with comparative rapidity by removal of the alkali, and changes to kaolin more readily than albite; but less so than labradorite, anorthite, and oligoclase.

It is always more or less crystal in porphyries and porphyritic schists. In massives it loses its crystal form with the increasing granularity of the mass, and never holds it in non-porphyritic schists. The crystals are frequently broken in massives from movement of the magma, and in schists from orogenic movements; but in the latter case the edges alone suffer. It twins most commonly after the Carlsbad law, less commonly after that of Baveno, least so after that of Manebach. It can be separated from the lime-soda feldspars by classification and sorting when the classification ratio is small. It can, further, be distinguished from them by the absence of striations, which generally exist in the plagioclases from their peculiar (albitic) twinning; but the flesh-red variety (or rather mixture) *perthite*, from Perth (Upper Canada), Egypt, etc., shows what seem to be striations, from the intercrystallization of parallel laminæ of orthoclase and albite. Orthoclase in quartzose eruptives is associated with hornblende rather than pyroxene. Potash feldspar and potash mica are commonly associated. In the older eruptives it occurs with nepheline more frequently than do the plagioclases.

5. Sanidine (Potash-soda Feldspar). Monoclinic. Tabular crystals, grains.

It behaves like orthoclase with the exception of showing more soda. Luster vitreous. Color grayish, yellowish white.

It occurs in extrusive rocks, as phonolite, trachyte,

pitchstone, etc.; has a fissured appearance due to the flow subsequent to crystallization; is found with quartz, plagioclase, nepheline, leucite, haüyne, and the black bisilicates.

THE ANORTHOCLASES (*Parorthoclases*, Zirkel).

These are all triclinic, but with slight deviation from a monoclinic habit, and their cleavage angle differs so little from that of orthoclase that they cannot be placed with the plagioclases. Some authorities hold that they are orthoclases deformed by slight pressure; as orthoclase under pressure assumes the microstructure of microcline, and the others of the group are monoclinic on heating. Zirkel rightly objects to the prefix *an-*, as it indicates a divergence, not a great similarity, and suggests *parorthoclase*.

6. Microcline (Potash Feldspar.) Triclinic. Never in perfectly bounded crystals; usually in irregular grains; twinned to form polysynthetic masses with both albite and pericline, which (masses) twin according to the three laws as with orthoclase.

H. 6–6.5; Gr. 2.54–2.57. Fracture uneven. Brittle. Luster vitreous, sometimes pearly. Color white to yellowish, red, green; by transmitted light colorless. Transparent–translucent. Comp. $KAlSi_3O_8$, like orthoclase, but carrying soda up to 5%, and lime to 1%. Bp. and chem. like orthoclase.

Microcline can only be safely distinguished from orthoclase by the microscope, as it occurs with it, and under similar conditions, so that it frequently replaces it. It is generally the feldspar in graphic granite (pegmatite); is common to granites, gneisses, syenites, and elæolite-syenites; less common in porphyries, and then only in the intratelluric crystals; almost wanting in the groundmass. It does not replace sanidine in the extrusives. Some authorities doubt the alteration of orthoclase to microcline by pressure, as it is found in cavities in rocks.

7 and 8. Anorthoclase and Cryptoperthite. Two species have thus far been agreed upon in the potash-soda mixtures, and a variety of names have been given them. Following Brögger, they are a potash-soda variety, *cryptoperthite*, and a soda-potash variety, *microperthite* (anorthoclase of Rosenbusch, parorthoclase of Zirkel). They are usually (*m*), though Fouqué reports anorthoclase crystals from Fayal 5 mm. long and 2 mm. thick.

Cryptoperthite (potash-soda variety) is assumed to be an interlamination of plates of orthoclase (or microcline) and albite of such minuteness as to be invisible under the microscope, and to act as a homogeneous body. The characteristics are similar to those of microcline. *Anorthoclase* (soda-potash variety), according to Fouqué, has Gr. 2.547–2.620—the heavier specimen coming from an olivine-andesite. The average is 2.580, that of microcline being 2.560. They twin polysynthetically, and the mass thus formed twins according to the three laws as with orthoclase. They are found in augite- and hornblende-andesites, augite-syenites, trachytes, rhyolites, and peculiar rocks of the island of Pantelleria called pantellerites.

THE PLAGIOCLASES.

The members of this group occur crystal, granular, and cryptocrystalline to compact. They are mixtures of a typical albite (L) and anorthite (N), as follows:

$$L = NaAlSi_3O_8$$
$$N = CaAl_2Si_2O_8$$

		Cleavage Angle.
Albite varies from	L_1N_0 to L_6N_1	86° 24′
Oligoclase "	L_6N_1 " L_3N_1	86° 08′
Andesine "	L_3N_2 " L_1N_2	86° 14′
Labradorite "	L_1N_1 " L_1N_3	86° 04′
Anorthite "	L_1N_6 " L_6N_1	85° 50′

On a fresh fracture, when the light falls somewhat obliquely on the basal (cleavage) plane, a striation generally appears, which is due to polysynthetic twinning of thin laminæ. While this is an indication of the group, its absence is not an indication of another group, as it is not quite universal. The crystals are never so large as the large orthoclases; but they show the same fractures. The microscope has shown that Breithaupt's laws of paragenesis are not universal; yet it can be noted that, as far as the unaided eye is concerned, the more acid plagioclases are the more usually found with orthoclase and quartz; while the more basic, as labradorite and anorthite, are generally absent under similar circumstances. The decomposition of rocks and resulting metachemic formation of secondary minerals frequently allows a determination of the ingredients of compact eruptives with a high degree of certainty, as shown by the microscope, or by following the mass to its centre where the crystals are large enough to be readily recognized. In some cases the materials for the secondary minerals have been leached from the country rock of the injected eruptive, and some authorities would extend this to all cases; but the fact that certain secondary minerals seem to favor rocks of definite mineralogical and chemical composition points to an origin within the rock. It is generally the case that an abundance of calcite or calcareous zeolites (chabazite, phillipsite, stilbite, etc.), in a compact basic eruptive enclosed in non-calcareous walls, is due to the decomposition of the minerals in the rock itself, and generally indicates the presence of a lime feldspar.

Association will frequently enable us to detect an obscure form of this group, as we find together frequently orthoclase and oligoclase, or orthoclase, oligoclase, and hornblende; labradorite and pyroxene or hypersthene; while we less seldom find together labradorite or anorthite and quartz,

or orthoclase and leucite, oligoclase and leucite or nepheline, etc. According to rapidity of weathering, the feldspars can be arranged in the following order, beginning with the most readily decomposed: labradorite, oligoclase, orthoclase, albite. If there be two feldspars in a rock and one be weathered, it may be possible to determine it by the unweathered one, from the general habit of association, together with the density of the rock.

9. **Albite** (Soda Feldspar).

H. 6–6.5; Gr. 2.62–2.65. Luster pearly on cleavages, otherwise vitreous. Color generally white, sometimes bluish, gray, reddish, greenish, green, but colorless by transmitted light when thin, as is the case of all the group. Transparent–subtranslucent. Fracture uneven. Brittle.

Bp. Fus. at 4 to a colorless glass and gives a strong flame reaction for Na. Chem. Untouched by acids.

It is found in granites and gneisses and the crystalline schists; in contact zones of diabase; in trachytes, andesites, phonolites, granular limestones, etc. Untwinned crystals are rare. Not weathered easily.

10. **Oligoclase** (Soda-lime Feldspar).

H. 6–7; Gr. 2.65–2.67. Luster vitreo-pearly or waxy to vitreous. Color usually white tinged with shades of grayish green, gray, green, and red. Transparent–subtranslucent. Fracture conchoidal, uneven.

Bp. Fus. 3.5 to clear enamel-like glass. Chem. Scarcely affected by acids.

It is necessary in diorite, trachyte, and andesite; is found with orthoclase in granite and syenite; is seldom found with leucite and nepheline. Occurs in massive grains and crystals, and twins according to the Carlsbad, albite, and pericline laws.

Weathers more readily than orthoclase and albite to kaolin and light-colored mica.

11. **Andesine** (Soda-lime Feldspar).

H. 5–6; Gr. 2.68–2.69. Color and luster similar to oligoclase.

Bp. Fus. 5 on thin splinters; with borax forms a clear glass. Chem. Soluble in HF; partially in the other acids. It occurs similarly to oligoclase in the eruptives and gneisses; weathers easily to kaolin, and twins like oligoclase.

12. **Labradorite** (Lime-soda Feldspar). Rarely crystal; lath-shaped; generally massive-granular; sometimes crypto-crystalline.

H. 6; Gr. 2.70–2.72. Luster pearly on basal cleavage; otherwise vitreous–subresinous. Color gray, brown, greenish, rarely white. Usually a play of colors on cleavage faces. Translucent–subtranslucent.

Bp. Fus. 3 to colorless glass. Chem. When fresh is with difficulty soluble in HCl, and leaves residue; when powdered is easily soluble in hot HCl.

Weathers like anorthite. It is confined to the basic eruptives and schists, is necessary to basalt and dolerite, abundantly developed in the Archæan rocks of Canada, and occurs chiefly in quartzless rocks, and seldom in those carrying nepheline and leucite.

13. **Anorthite** (Lime Feldspar). Generally non-crystal, and in lath-shaped, granular, and spathic forms.

H. 6–7; Gr. 2.66–2.78. Luster somewhat like labradorite. Color white, grayish, reddish. Transparent–translucent. Fracture conchoidal. Brittle.

Bp. Fus. 4.5–5 to colorless glass. Chem. Decomposed by HCl with separation of gelatinous silica.

It is found in a few diorites (corsite); in diabase, gabbro, norite, and basic schists that have probably been metamorphosed from gabbros. In Vesuvian lavas it occurs in greasy

crystals when in the mass, but in limpid and vitreous ones when in druses. It weathers easily.

THE MICAS.

The members of this group are monoclinic, but are peculiar in having a hexagonal or orthorhombic habit in their crystals and physical characteristics. They generally form folia in rocks with exact hexagonal outline when crystal, and frequently they have considerable thickness; but the usual habit is the basal plane with irregular boundaries. These folia can be distinguished from those of the chlorite group by their elasticity, the latter being perfectly flexible, and the elasticity increases with the acidity of the mica, while brittleness increases with the basicity. They can thus be arranged, according to amount of silica, *lepidomelane* (laminæ brittle and little elastic), *biotite*, *phlogopite*, *lepidolite*, *muscovite*, the last being very tough and elastic. Frequently the mica will be a mixture of muscovite and biotite, and always following the law that the muscovite is external, whether as the rim of a single plate or as the outside plates of a crystal series. This mixture cannot be detected by the eye, and only chemically when the mass is large.

The Acid Micas.

14. Muscovite (Potash Mica).

H. 2–2.5; Gr. 2.83–2.9. Luster vitreous-pearly. Thin laminæ flexible and elastic. Color white, gray, brown, green, yellow, violet, rarely red; by transmitted light, light shades of yellow and green. Transparent–translucent. Comp. $H_2KAl_3Si_3O_{12}$.

Bp. In closed tube gives water that frequently reacts for fluorine; whitens and fus. 5.7 to a gray or yellow glass; with fluxes reacts for iron; sometimes Mn, rarely Cr;

decomposed by fusion with alkaline carbonates. Chem. Slightly attacked by acids.

It is an essential in granite and gneiss, and is found in a few quartz-porphyries; never in eruptives other than above given. We find muscovite associated with quartz and potash feldspar in granitoid rocks. It is not commonly found in porphyries.

Weathers to steatite and serpentine, and is itself an alteration product of other minerals. Among its varieties are:

14a. Damourite (Hydromica).

A variety of muscovite that is extended to include (Dana) most hydromicas, margarodite, sericite, etc. They may give off more water in the closed tube than does muscovite; but they do not contain any more chemically combined. Folia less elastic. Luster pearly or silky. Feel like talc (formerly much hydromica schist was called talc-schist until distinguished by Dewey). Its difference is shown by the action of the two with cobalt solution and HF.

14b. Agalmatolite (Pagoda Stone). Compact, amorphous.

Luster feeble, waxy. Color grayish, greenish, yellowish. Like a compact muscovite, and produced from the alteration of iolite, spodumene, scapolite, and similar minerals. The Chinese variety has H. 2–2.5; Gr. 2.78–2.81. Part of the Chinese agalmatolite is pinite, which is a similar alteration product, but with less silica; part is compact pyrophyllite, and part is steatite. It is used for carving miniature images, etc.

15. Paragonite (Soda Mica).

H. 2.5–3; Gr. 2.78–2.90. Luster pearly. Color yellowish, grayish, greenish; colorless by transmitted light. Translucent, and smaller scales transparent. Comp. $H_2NaAl_3Si_3O_{12}$.

Bp. Fusible with difficulty; some varieties whiten on edges and exfoliate. Occurs in crystalline schists and phyllites,

in irregularly bounded plates and fine scaly aggregates looking like talc; never in massives.

16. **Lepidolite** (Lithia Mica). Commonly massive, scaly, granular.

H. 2.5–4; Gr. 2.8–2.9. Luster pearly. Color peach-blow red, rose-red, violet gray, yellowish, greenish, white; colorless by transmitted light. Translucent. Comp. $Al(SiO_4)_3Al_2KLiH + Al(Si_2O_5)_3K_2Li_2(AlF_2)_2$.

Bp. In closed tube gives water and reaction for F. Fus. 2–2.5 with intumescence to a whitish or grayish glass, and sometimes gives the lithia-flame reaction; with fluxes some varieties react for Fe and Mn. Chem. Only partially decomposed by acids before fusion; after, it gelatinizes with HCl. Occurs in granite, gneiss, and pegmatitic secretions from them.

17. **Zinnwaldite, Lithionite** (Lithia-iron Mica).

H. 2.5–3; Gr. 2.82–3.21. Luster often pearly. Color like lepidolite with brown shades and darker gray; by transmitted light dark brown to light yellow and grayish white. Fine wrinkling on cleavage plane from twinning.

Bp. Similar to lepidolite, but fuses more easily and gives F reaction. Comp. $(K,Li)_2FeAl_2Si_3O_{10}(OH,F)$. Occurs in tin-bearing granites in Germany, France, Cornwall, etc., and in pegmatitic secretions in granite and gneiss; necessary in greisen.

18. **Biotite** (Magnesia-iron Mica).

H. 2.3–3; Gr. 2.7–3.1. Luster splendent-pearly on cleavages, black kinds submetallic; lateral surfaces vitreous. Color green-black; deep black in thick crystals; by transmitted light brown in Archæan rocks; frequently green with hornblende of similar color, but not in massive porphyries, and rare in granites. Transparent–opaque. Comp. $(HK)_2(Mg,Fe)_4(Al,Fe)_2Si_4O_{16}$.

Bp. Water in closed tube; in open tube reaction for F

and for Fe; with fluxes varies greatly in different varieties; whitens on thin edges and fuses. Chem. Completely decomp. by H_2SO_4 with separation of silica in thin scales.

Occurs in massives and Archæan rocks—not in crystals, but as flakes and plates with irregular boundaries. In granites it is intergrown with muscovite, as has been described on p. 25. It is one of the first generations in porphyritic rocks, and is generally absent from the second generations in the groundmass; is one of the most common results of contact metamorphism, and is often an alteration product of chlorite. It is more abundant in acid than basic rocks.

(*a*) Rubellan is an altered ferruginous biotite found in some basalts.

19. **Phlogopite** (Magnesia Mica). In crystals and plates.

H. 2.5–3; Gr. 2.78–2.85. Thin laminæ are tough and elastic. Luster pearly, often submetallic on cleavages. Color yellowish brown, brownish red with copper-like reflections; also pale brownish yellow, green, white, colorless. A small candle flame viewed through thin plates shows commonly a six-rayed star due to acicular inclusions. Transparent–translucent. Comp. $H_6K_2Mg_7Al_2(SiO_4)_6$, so that it may be called a biotite lacking iron.

Bp. In closed tube gives little water; frequently in open tube a small amount of F; with fluxes little or no iron; whitens and fuses on thin edges. Chem. Like biotite; alters to talc. Occurs mostly in Archæan granular limestone; also in serpentine.

20. **Lepidomelane** (Iron-magnesia Mica). Tabular, massive.

H. 3; Gr. 3–3.2. Luster adamantine-vitreous or pearly. Color black with greenish reflection. Streak grayish green. Translucent in thin laminæ, otherwise opaque. Somewhat

brittle. Comp. $(H,K)_2Fe_2(Fe,Al)4(SiO_4)_3$. This is a ferric biotite.

Bp. At red heat turns brown and fuses to a black magnetic globule. Chem. Most easily of all micas decomposed by acids, and by HCl readily with separation of silica scales. Occurs more restrictedly than biotite in granite, etc.

Brittle Micas.

21. Margarite (Pearl Mica). Tabular, scaly, massive.

H. 3.5–4.5; Gr. 2.99–3.08. Brittle. Luster of base pearly. Color grayish, reddish, yellowish, white. Transparent–subtranslucent. Comp. $H_2CaAl_4Si_2O_{12}$.

Bp. Water in closed tube; whitens and fuses on edges. Chem. Slowly and imperfectly decomposed by boiling H_2SO_4. Commonly associated with corundum in contact formations.

(*a*) Ottrelite and phyllite belong here, and are found only in crystalline schists.

CHLORITES.

The color of these green minerals is due to ferrous iron and gives them their name. They are sometimes red or brown; of low hardness and with flexible laminæ — tough and not elastic. They are all monoclinic in habit, though they simulate hexagonal shapes, as the angles about the basal plane are 120°. Chem. they are (ferrous) iron-magnesian silicates of aluminum with chemically combined water and no alkalies, and seem to be altered from rich iron-magnesia silicates (hornblende, pyroxene, biotite, phlogopite, etc.). They occur generally in flat or bent laminæ, and are attacked by acids.

22 Clinochlore (Magnesia-iron Chlorite). Crystal, coarse scaly granular, earthy, massive.

H. 2–2.5; Gr. 2.65–2.78. Luster pearly on cleavages. Color deep grass-green–olive green, pale green–yellowish, white, also rose and red (chromium variety) by transmitted

light green or yellow-brown. Transparent-translucent. Comp. $H_8Mg_8Al_2Si_3O_{18}$.

Bp. Gives water; whitens and fuses with difficulty on thin edges of small pieces to a grayish-black glass; with borax reacts for Fe (sometimes Cr); some kinds exfoliate. Chem. Wholly decomposed by H_2SO_4.

23. Penninite (Magnesia-iron Chlorite). Flat or bent laminæ, massive, compact cryptocrystalline.

H. same as 22; Gr. 2.6–2.85. Luster, etc., like 22.

Bp. Water in closed tube; exfoliates slightly and fuses with difficulty; reacts for Fe (and Cr in many cases). Chem. Like 22, and also partly decomposed by HCl.

24. Prochlorite (Iron-magnesia Chlorite). Massive, foliated, granular.

H. 1.–2.; Gr. 2.78–2.96. Luster of cleavages feebly pearly. Color darker shades of green; by transmitted light green (sometimes red). Streak more generally uncolored than that of the others. Opaque-transparent only in thin folia. Comp. $H_4(Mg,Fe)_3Si_3O_9$.

Bp. same as 22.

The chlorites are most widely distributed and give to many eruptives their green color. They also occur in the basic schists. Prochlorite occurs most frequently in eruptives, the other two in the schists. The cromium varieties are found in olivine-bearing schists.

THE PYROXENES

These are widely distributed eruptive and schistose rock-formers, which crystallize in orthorhombic, mono-, or triclinic forms; but agree in having an angle of 87° and 93° to the fundamental prism, and a more or less distinct cleavage parallel to it.

Orthorhombic Section.

25. Enstatite. Rarely crystal, usually massive, fibrous, lamellar.

H. 5.5; Gr. 3.1–3.3. Luster on cleavages subpearly–vitreous (metalloidal in bronzite). Color grayish, yellowish, or greenish white, olive-green, brown; by transmitted light enstatite is grayish–yellowish white, and bronzite yellowish, greenish. Streak uncolored–grayish. Translucent–nearly opaque.

Bp. Fus. 6. Chem. Insoluble in HCl.

(*a*) *Enstatite.* Comp. $MgSiO_3$; color white with shades of yellow, green, and gray. Luster vitreo-pearly. Gr. 3.10–3.13.

(*b*) *Bronzite.* (Magnesia - iron. Enstatite). Comp. $(Mg,Fe)SiO_3$. Color grayish or olive-green, brown. Luster of cleavages adamantine–pearly (the submetallic or bronzy luster that gives it its name is not essential, as it is the result of alteration). It is intermediate between enstatite and hypersthene, and has Gr. up to 3.3.

The enstatites are found massive in gabbro, norite, granular peridotites, and the derived serpentine. Crystals are rare and found in porphyritic rocks with monoclinic pyroxene; also in trachytes and andesites, and in schists. They alter to talc, serpentine, and,

Bastite (Schiller Spar). H. 3.5–4; Gr. 2.5–2.7. This comes mostly from bronzite and shows highly its peculiar luster (schiller). It occurs in granular eruptives and is completely decomposed by H_2SO_4.

26. Hypersthene. (Iron-magnesia Enstatite.) Sometimes tabular, usually foliated, massive, crystals rare, sometimes in thin prisms.

H. 5–6; Gr. 3.40–3.50. Luster subpearly on cleavages, frequently metalloidal. Color darker shades of the enstatite colors, brownish green, grayish black, greenish black; by transmitted light, light red, brown–red. Translucent–nearly opaque; streak grayish, brownish gray. Comp. $(Fe.Mg)SiO_3$

and sometimes with Al_2O_3, so that it approximates to the aluminous species of this group.

Bp. Fuses to a black enamel, and gives on charcoal a magnetic mass. Chem. Partially decomposed by HCl.

Occurs in masses in gabbro, norite; in prisms in porphyrites, trachytes, andesites, and lavas; not found in true Archæan rocks, except when it is metachemized; alters to limonite, hornblende, actinolite, bastite, etc.

Comparison of enstatite (*a*), bronzite (*b*), and hypersthene (*c*): (*a*) and (*b*) have their best cleavage parallel to the rhombic prism; have generally lighter colors and lower specific gravity; are almost infusible Bp. and untouched by HCl. (*c*) has the best cleavage parallel to brachypinacoid; has darker colors; is fusible and partially decomposed by HCl. (*a*) and (*b*) are often fibrous, (*c*) not so.

Monoclinic Section.

27. Pyroxene. Crystal, lamellar, granular, rarely fibrous or columnar. A (*m*) form in magmas rich in alkalies is that of an hourglass.

H. 5–6; Gr. 3.2–3.6 (as a rock-former never less than 3.3). Luster vitreous–resinous, sometimes pearly. Color colorless through greenish or yellowish shades to brown and black. Streak white–gray or grayish green. Transparent–opaque. Pyro-electric; comp. $RSiO_3$, R being commonly protoxides of Ca, Mg, and Fe; less commonly Mn and Zn; rarely K and Na, and in small per cent; sometimes also sesquioxides of Fe, Mn, and Al. Chem. Generally untouched by acids. The varieties are:

NON-ALUMINOUS.

(*a*) Diopside (Malacolite). Slender prismatic crystals, columnar masses. Gr. 3.2–3.38. Color white with light shades of yellow, gray, and green; also dark green to black (in ferrous varieties); sometimes transparent and colorless;

by transmitted light colorless to light greenish; sometimes brown. Comp. $Ca,Mg(SiO_3)$.

Bp. Fus. 3.75. Occurs sparingly in eruptives (augite-granite, diabase, quartz-prophyry, minette, kersantite), but widely disseminated in Archæan rocks and granular limestones.

(*b*) Diallage. Massive lamellar, thin foliated, generally not crystal, but crystalline, also fibrous, and interlaminated with an orthorhombic pyroxene.

H. 4; Gr. 3.2–3.35. Luster pearly, sometimes metalloidal. Color greenish shades and brown; like diopside by transmitted light. Comp. also like it, but with Al_2O_3, which makes it approach augite. Bp. and chem. like diopside.

Necessary in gabbro and derivatives; essential in some peridotites and serpentines; sparingly in basaltic and andesitic extrusions in prisms; infrequent in Archæan rocks, and confined to olivine-bearing massives and schists and their derivatives; metachemized to serpentine and chlorite; metamorphosed to amphibole on gabbro-phyllite contacts.

ALUMINOUS.

(*c*) Augite. ($CaMgSi_2O_6$) with $(Mg,Fe)(Al,Fe)_2SiO_6$. Usually short prismatic crystals; also in irregular columns and grains.

H. and Gr. as first given. Color greenish or brownish black to black; by transmitted light green, brown, rarely yellow, red, or violet.

Bp. Fus. 3; in general the ferruginous varieties of pyroxene give a magnetic globule on charcoal, and the greenish and yellowish kinds become reddish brown by heating on platinum foil from the formation of ferric oxide.

This is one of the commonest components of crystalline rocks. In the extrusives it is more commonly crystal; in the granitoid massives it occurs in irregular columns; not

found in the crystalline schists unless the greenish monoclinic pyroxenes in them are augite instead of a dark diopside. The light green variety, omphacite, is found in eclogites in rounded grains or short columnar aggregates.

Pyroxene is necessary in the basalt-gabbro series, and essential in many rocks. Diallage is necessary in gabbro. Pyroxene alters to chlorite and thence to carbonates, limonite, clay, and quartz; by uralitization to hornblende, to talc, serpentine, epidote, glauconite, mica. According to Rosenbusch, the pyroxenes in acid and alkaline rocks are green, in basic extrusives brown, in crystalline schists colorless to greenish.

28. Acmite. (Ægerite.) (Lime-soda Pyroxene.) Long prisms.

H. 6–6.5; Gr. 3.50–3.55. Luster vitreous–resinous. Streak pale yellowish gray. Color brownish or reddish brown, green; by transmitted light green, brown to violet. Subtransparent–opaque. Comp. $Na_2(Fe_2)Si_4O_{12}$.

Bp. Fus. 2 to lustrous black magnetic globule, coloring the flame deeply yellow; with fluxes reacts for Fe and Mn. Chem. Slightly acted on by acids.

Occurs in elæolite-syenite and augite-syenite of Canada, New Jersey, and Norway; in sodalite-granite of Greenland, at Ditro; in acid lavas of San Miguel, Azores; in alkaline granites rich in soda, acmite-trachyte, etc.

Triclinic Section.

29. Hiortdahlite. Crystals tabular and vertically elongated.

H. 5–5.6; Gr. 3.267. Luster vitreous on crystal faces, greasy on fractures. Color light shades of straw-, sulphur-, to honey-yellow; less often yellowish brown. Comp. nearly $4Ca(Si,Zr)O_3.Na_2ZrO_2F_2$. Bp. Fus. easily to yellowish white enamel. Chem. Gelat. with acids. The crystals are 5–10 mm.

long and 2–3 mm. broad, and resemble wöhlerite; but gr. is lower, bp. fuses more easily. Occurs in elæolite-syenite in Norway.

THE AMPHIBOLES.

These dark-colored bisilicates rank next to the pyroxenes in wideness of diffusion, and like them are grouped in the same crystallographic systems. There are fewer species than in the former group; but these show close parallels with similar pyroxenes. The prismatic angles are 56° and 124°; the other differences will be discussed later.

Orthorhombic Section.

30. **Anthophyllite.** Crystals rare, unterminated prisms, commonly lamellar and without definite boundaries, fibrous massive, with slender fibers, in prismatic aggregates like actinolite.

H. 5.5–6; Gr. 3.15–3.24. Luster vitreo-pearly on cleavages. Color grayish, yellowish, and greenish brown, emerald-green, sometimes metalloidal. Streak uncolored or grayish. Transparent–translucent. Comp. $(Mg,Fe)SiO_3$, or like the enstatite-hypersthenes.

Bp. Fusible with difficulty to a black magnetic enamel; reacts for Fe with fluxes. Chem. Untouched by acids. Varieties:

(*a*) *Anthophyllite* (Mg-Fe-Anthophyllite). Prismatic angle 54° 23′; corresponds to enstatite.

(*b*) *Gedrite* (Al-Fe-Mg-Anthophyllite). Prismatic angle 54° 40′; corresponds to hypersthene.

These are generally restricted to the hornblende gneisses and schists among unaltered rocks; occurs abundantly in olivine serpentines. Alteration products unknown.

Monoclinic Section.

31. Amphibole. Prismatic, columnar, fibrous, rarely lamellar, granular-massive.

H. 5–6; Gr. 2.9–3.4. Fracture subconchoidal, uneven. Brittle. Luster vitreous. Color from black to white through shades of green and brown, rarely reddish, yellowish. Sometimes transparent, usually translucent. Varieties:

SLIGHTLY OR NON-ALUMINOUS.

(*a*) *Tremolite* (Ca-Mg-Amphibole). Crystals long-bladed and short and stout, thin columnar, fibrous, compact granular massive.

H. 5–6; Gr. 2.9–3.16. Color white to dark gray; colorless by transmitted light. Occurs in Archæan granular limestone, in altered olivine rocks and serpentines. Alters to talc.

(*b*) *Actinolite* (Ca-Mg-Fe-Amphibole). Prismatic individuals, columnar and fibrous aggregates, granular-massive.

Gr. 3–3.2. Sometimes transparent. According to thickness and arrangement of fibers it is *glassy*, *asbestiform*, and *radiated;* color green from ferrous iron, and same by transmitted light. Occurs principally in Archæan basic schists; necessary in actinolite-schist; also in metachemized diabase and gabbro. The *Smaragdite* in saussurite-gabbro is a slightly aluminous actinolite.

(*c*) *Asbestus* is a finely fibrous tremolite, actinolite, or other slightly or non-aluminous amphibole.

(*d*) *Uralite* is a paramorph of hornblende after pyroxene, in which the crystals have the habit of the latter and the cleavage, gr., and optical characteristics of the former. Occurs in diabase, diabase-porphyrites interbedded with schists, augite-diorite, augite-syenite, etc.

(*e*) *Nephrite* (Jade) is a compact and fine-grained tremolite or actinolite. H. 6–6.5; Gr. 2.96–3.1. Fracture splintery. Luster glistening. Occurs in eastern Siberia and New Zealand.

ALUMINOUS.

32. Hornblende (Pargasite) (Al-Fe-Mg-Ca-Amphibole). Crystals, prismatic individuals. The lighter green kinds are sometimes called pargasite and the darker ones hornblende; but E. S. Dana says that no line can be drawn between them from this or any other characteristic. Gr. 3.05–3.47. Color green, bluish green, greenish black, black. Varieties:

(*a*) Ordinary hornblende with color generally green, sometimes deep brown and brownish red. Occurs in porphyritic states of granite, syenite, and diorite; granular massives of the Archæan. Alters to chlorite, thence to clay, carbonates, limonite, and quartz.

(*b*) Basaltic hornblende with color black; by transmitted light brown in all directions. Always in crystals. Becomes greenish on altering. Occurs only in porphyritic extrusives. The bp. and chem. tests are as in pyroxene.

33. Arfvedsonite (Al-Na-Amphibole). Imperfect crystals and massive.

H. 5.5–6; Gr. 3.44. Luster vitreous. Color pure black, in thin scales deep green or brown. Streak grayish green. Opaque, except in thin splinters. Fracture subconchoidal.

Bp. Fuses at 2 with intumescence to a black magnetic globule; colors the flame yellow (soda), and reacts with fluxes for Fe and Mn. Chem. Not touched by acids. Comp. about $4Na_2O,3CaO,14_2FeO,(Al,Fe)_2O_3,21SiO_2$. Occurs in elæolite-syenites and other rocks poor in silica and rich in soda.

34. Glaucophane (Al-Na-Amphibole). Commonly massive fibrous, or columnar to granular.

H. 6–6.5; Gr. 3.103–3.044. Luster vitreous to pearly. Color azure-blue, lavender-blue, bluish black, grayish. Streak grayish blue. Translucent. Fracture conchoidal to uneven. Brittle. Comp. $NaAl(SiO_3)_2(Fe,Mg)SiO_3$. Prismatic cleavage angle 58° 16′. Recognized by its blue color. Occurs in glaucophane-schist; less frequently in mica-schist, gneiss, eclogite; altered from diallage.

35. Riebeckite (Fe-Na-Amphibole). Unterminated prismatic crystalloids.

H. 5–6; Gr. 3.3. Luster vitreous. Color black. Comp. $2Na_2Fe(SiO_3)_2.FeSiO_3$, corresponding closely to acmite (28). Prismatic cleavage 56° perfect. Occurs in keratophyre, quartz-keratophyre, and minette, gneiss, soda granite.

36. Ænigmatite (Cossyrite). Prismatic crystals; angle 66°.

H. 5–6; Gr. 3.80 (Ænig.), 3.74 (Coss.). Luster vitreous. Color black; brownish black by transmitted light. Streak reddish brown. Translucent to opaque. Comp. titano-silicate of ferrous iron and sodium, with sesquioxides of iron and alumina.

Bp. Fusible easily to brownish-black glass. Chem. Partly decomposed by acids. Ænigmatite occurs in large crystals in the elæolite-syenite of Norway; cossyrite in small crystals in the rhyolite lavas of the island of Pantelleria.

COMPARISON OF THE PYROXENE AND AMPHIBOLE GROUPS.

Prismatic angle with pyroxene 87° and 93°; with amphibole 56° and 124°. Prismatic cleavage more distinct in amphibole. Crystals in pyroxene stouter, and the massive kinds lamellar and granular; in amphibole they are long, prismatic, and fibrous. In corresponding kinds the gr. is one tenth higher in pyroxene. Pyroxene has more lime; amphibole more magnesia and alkalies. Of the rock-makers the gr.

of pyroxene is never less than 3.3; that of amphibole always so. Amphibole is associated with the more acid rocks, soda and potash feldspars, potash mica, and pyrite; pyroxene with basic rocks, leucite, olivine, and labradorite. That they are closely isomorphous is shown by the fact that of twinned forms one is frequently pyroxene and the other amphibole.

THE EPIDOTES.

37. **Zoisite** (Ca Al-Epidote). Orthorhombic, crystal, prismatic aggregates, massive, compact.

H. 6–6.5; Gr. 3.25–3.37. Luster vitreous and pearly on most perfect cleavage. Color grayish white, gray, yellowish brown, greenish gray, apple-green; also shades of light red; by transmitted light colorless, gray, greenish gray. Comp. $HCa_2Al_3Si_3O_{13}$. It graduates into epidote by the addition of **iron.**

Bp. Fusible at 3.5 with intumescence to a white blebby mass and gives much water. Chem. Undecomposed by acids unless previously heated to redness, and then gelatinizes with HCl. Occurs in the crystalline hornblende-schists. The variety

(*a*) Saussurite is compact and tough with splintery fracture. H. 6.5–7; Gr. 3–3.4. Color white to gray with greenish shades. Translucent to opaque. Not homogeneous, but the result of dynamo-metamorphism of a plagioclase. With smaragdite forms euphotide; also present in saussurite-gabbro.

This name has also been applied to forms of garnet, meionite, labradorite. Many European authorities place it under labradorite; J. D. Dana, from its high gr., and Sterry Hunt, from its chem. comp., put it as above. They are followed by Zirkel, who names authorities of the same opinion; Rosenbusch puts it under epidote.

38. **Epidote** (Ca-Al-Fe-Epidote). Monoclinic, seldom sharply defined crystals, usually fibrous-granular-massive.

H. 6–7; Gr. 3.25–3.5. Luster vitreous, but pearly to resinous on the orthopinacoid. Color shades of green to black; also red, yellowish, gray; by transmitted light colorless, pale yellow, rarely yellowish brown, pale green, seldom red. Comp. $HCa_2(Al,Fe_2)Si_3O_{13}$. The greater density over zoisite is due to iron.

Bp. Water in closed tube on strong heating; fusible at 3–3.5 with intumescence to dark brown or black mass; magnetic in the darker shades; gives iron with the fluxes. Chem. Decomp. by fus. with alkaline carbonates, and by HCl with gelatinization after heating to redness; otherwise untouched by acids.

The commonest of metachemic minerals, and seldom, if ever, occurs as an original component in rocks. (Keyes thinks that the occurrence of epidote with allanite in the Maryland granite shows it to be a primary mineral.) Occurs in crystalline massives and schists as an alteration of the iron-amphiboles, as granite, syenite, mica- and hornblende-schists, serpentine, etc. Alters with difficulty, as all the elements have peroxidized. Variety:

(*a*) Piedmontite (Mn-Epidote). Gr. 3.404. Bp. Fusible at 3.5 to a lustrous glass; otherwise like epidote. Common in the crystalline schists of Japan and altered pre-Cambrian rhyolites of Pennsylvania and Maryland.

39. **Allanite** (Cerium, etc., Epidote). Tabular crystals, massive, granular.

H. 5.5–6; Gr. 3.5–4.2. Brittle. Fracture uneven. Luster submetallic, pitchy, resinous. Color dark brown to black with shades of green and yellow; by transmitted light reddish brown, greenish brown. Subtranslucent to opaque. Comp. like epidote, but with partial substitution of Fe for Ca, and Ce, La, Di, Y, and Er for Al.

Bp. More or less water on strong heating in closed tube; fus. 2.5 with results like epidote; reacts for Fe with fluxes. Chem. Unlike epidote and zoisite, as it gelatinizes with HCl only before ignition; untouched after. Occurs in gneiss, granite, granite-porphyry, quartz-porphyry, diorite-porphyrite, andesite, rhyolite, dacite. Alters with yellow crust, but generally fresh in rocks.

LEUCITE-NEPHELINE-SODALITE GROUP.

These are silicates more or less common to eruptives containing the black bisilicates. They are found with, and more or less replace, the plagioclases in them. All have H. 5–6; Gr. 2.14–2.6.

40. **Leucite.** Tetragonal at ordinary temperatures, but isometric at 500° C. commonly crystal, in disseminated grains, rarely massive.

H. 5.5–6; Gr. 2.45–2.50. Luster vitreous. Color white, grayish. Translucent to opaque. Comp. $KAl(Si_2O_6)$.

Bp. Infusible; gives blue of Al with cobalt solution. Chem. Slightly attacked by HCl in the solid, but decomp. without gelat. when powdered. Occurs in Tertiary and post-Tertiary extrusives; in older rocks metachemized to allied forms; found in leucite-basalts, leucite rock, phonolite, etc.; is not found with free quartz. Alters to feldspar, nepheline, and kaolin.

41. **Nepheline** (Elæolite). Hexagonal, stout, prismatic, thin-columnar, granular-massive, compact.

H. 5.5–6; Gr. 2.55–2.65. Fracture subconchoidal. Brittle. Luster vitreous to greasy. Color colorless, yellowish (nepheline), and when massive greenish and reddish shades (elæolite). Comp. $K_2Na_2Al_2Si_2O_8$.

Bp. Fus. 3.5 quietly to a clear glass. Chem. Gelatinizes with acids.

Nepheline bears the same relation to elæolite that sani-

dine does to orthoclase, and both are found under similar conditions.

(*a*) *Nepheline* is the glassy crystalline form found in the younger effusives, and with Gr. 2.56. Occurs in phonolites, nepheline-basalts, and with sanidine.

(*b*) *Elæolite* is the coarser crystalline and generally massive form, variously colored, that occurs in older intrusive rocks, and frequently associated with orthoclase. Gr. 2.59–2.65. Occurs in elæolite-syenite, miascite, ditroite, augite syenite.

Both alter to thomsonite, analcite, sodalite, natrolite, pinite, and kaolin.

42. **Cancrinite.** Hexagonal, usually massive.

H. 5–6; Gr. 2.42–2.5. Color white to gray, yellow, green, blue, reddish; by transmitted light colorless. Luster subvitreous with pearly or greasy film. Transparent to translucent. Comp. $4Na_2O,4Al_2O_3,9SiO_2 + 2CaO,CO_2 + 3H_2O$.

Bp. Water in closed tube; fuses at 2 with intumescence and loss of color to a white blebby glass (being thus distinguished from nepheline). Chem. Effervesces with HCl, and after heating forms a jelly. Occurs in elæolite-syenite. Alters to natrolite.

43. **Sodalite.** Isometric, prisms, grains, massive.

H. 5.5–6; Gr. 2.14–2.30. Luster vitreous–greasy. Color white and light shades of green, blue, yellow, and red; shows the same by transmitted light and colorless. Comp. $Na_4(AlCl)Al_3Si_3O_{12}$.

Bp. In closed tube the blue kinds become white and opaque; fuses at 3.5–4 with intumescence to a colorless glass, and with microcosmic salt and oxide of copper gives bluish flame-coloration due to chlorine. Chem. Decomp. by HCl with separation of gelatinous silica. Occurs as essential in elæolite-syenite; crystallizes in rocks after augite

and before nepheline and the feldspars; alters to thomsonite, muscovite, natrolite, and kaolin.

44. Haüyne. Isometric, rounded grains.

H. 5.5–6; Gr. 2.4–2.5. Fracture flat-conchoidal. Brittle. Luster vitreous-greasy (like sodalite and nepheline). Color bright shades of blue and green, red, yellow; by transmitted light the same and colorless. Subtransparent-translucent. Comp. $2(Na_2O,Al_2O_3,2SiO_2) + Na_2O,SO_3$, with Na partly replaced with Ca. There are two varieties:

(*a*) *Haüyne* with considerable Ca. Bp. Retains its color in closed tube, and is thus distinguished from sodalite; fuses at 4.5 to white glass; gives sulphur reaction with soda on charcoal. Chem. Decomposed by HCl with separation of gelatinous silica.

(*b*) *Nosean* (Soda Haüyne).

H. 5.5; Gr. 2.25–2.4. Color grayish, bluish, brownish, black. Translucent-opaque. Otherwise like haüyne, except that haüyne gives H_2S on heating with H_2SO_4, and has the stronger blue color; but nosean takes a bright blue on heating, owing to a change in the sodium sulphide. The red color of haüyne is due to ferric scales. Occurs in basalt, phonolite, and extrusives poor in quartz and alkali.

45. Melilite. Tetragonal, usually in short square prisms, also in irregular grains.

H. 5; Gr. 2–3.10. Luster vitreous. Color white, shades of yellow and brown. Translucent to opaque. Comp. $(Ca,Mg)_6(Al,Fe)_2Si_3O_{10}$.

Bp. Fuses at 3 to a yellowish greenish glass; gives Fe with fluxes. Chem. Gelatinizes with HCl. Occurs in the extrusives and abundant in leucite and nepheline rocks, and often replaces the feldspars so as to be necessary to the species.

46. Olivine (Chrysolite, Peridot). Orthorhombic, usu-

ally in imbedded grains, massive and compact or granular. The precious form (chrysolite) is not a rock-former

H. 6.5–7; Gr. 3.3–3.45. Luster vitreous. Color commonly olive-green and changing to yellowish brown or red on oxidation of the iron ingredients; by transmitted light colorless to greenish white. Comp. $(Mg,Fe)_2SiO_4$.

Bp. Whitens, but is infusible; reacts for iron with fluxes. Chem. Decomposed by HCl and H_4SO_4 with separation of gelatinous silica. Alters to carbonates, silicates, serpentine, limonite, and in Archæan rocks to amphiboles. Occurs in basic granular eruptives and basic crystalline schists; sometimes accessory and sometimes essential and necessary. Varieties:

(*a*) *Hyalosiderite* (Ferruginous Olivine). Gr. 3.57. Bp. Fuses to a black magnetic globule; otherwise like olivine.

(*b*) *Fayalite* (Iron-olivine). Gr. 4–4.14. Luster metalloidal. Color light yellow to black through shades of brown due to oxidation. Comp. Fe_2SiO_4. Bp. Fuses easily to a magnetic globule; otherwise like olivine. Occurs in extrusives, among them rhyolite from Yellowstone Park.

Olivine is distinguished from quartz by its yielding to acids, fusibility, and Fe reaction with borax.

SERPENTINE-TALC GROUP.

47. **Serpentine.** Monoclinic, in pseudomorphs, sometimes foliated and fibrous, usually amorphous.

H. 2.5–4 (rarely 5.5); Gr. 2.50–2.65. Luster feebly greasy, waxy. Color shades of green and brownish yellow, sometimes nearly white; by transmitted light transparent with shades of green and yellow. Translucent–opaque. Comp. $H_4Mg_3Si_2O_9$.

Bp. gives water; fus. 6 on edges; reacts for Fe. Chem. Decomposed by HCl and H_2SO_4, and more vigorously in proportion to the heat of the acids. Widely distributed

and frequently in large masses, and results from the alteration of peridotite and other rocks.

Serpentine is distinguished from pyrophyllite and talc by its complete decomp. by H_2SO_4, pyrophyllite being only partially decomp., talc not at all. Talc gives a red color (Mg) with cobalt solution on heating, while pyrophyllite gives blue (Al).

48. Talc. Orthorhombic or monoclinic, usually foliated, massive, also granular-massive.

H. 1–1.5; Gr. 2.7–2.8. Sectile. Thin laminæ, not elastic. Luster pearly. Color shades of green from white to blackish. Comp. $H_2Mg_3Si_4O_{12}$.

Bp. gives water generally after hard heating; whitens, exfoliates; fuses at 5.5 on thin edges to a white enamel; red color (Mg) on heating with cobalt solution, and is thus distinguished from muscovite. Chem. Not decomposed by acids; important in crystalline and metamorphic schists.

49. Pyrophyllite. Monoclinic, foliated, granular-compact or cryptocrystalline.

H. 1–2; Gr. 2.28–2.9. Color rather more yellowish than talc. Comp. $H_2Al_2Si_4O_{12}$ (an aluminous talc).

Bp. Water at high temperature; whitens and fuses at 6 on thin edges; radiated variety exfoliates; gives blue color (Al) with cobalt solution. Chem. Partly decomposed by H_2SO_4 and completely by fusion with alkaline carbonates. Occurs in crystalline schists.

The two following minerals are found generally in eruptives in microscopic proportions, and are among the first to crystallize. Their crystals are therefore included in those formed later. They also occur of macroscopic proportions.

50. Zircon. Tetragonal, crystal, never massive.

H. 7.5; Gr. 4.68–4.70. Luster adamantine. Color colorless to brownish shades of yellow; by transmitted light,

light yellow, pink, and violet. Transparent–opaque. Comp. $ZrSiO_4$.

Bp. Infusible; not acted on by microcosmic salt; decomposed when powdered and fused with soda on a platinum wire, and gives with turmeric paper the orange color for Zr when treated with HCl. Chem. When powdered is decomposed by hot H_2SO_4; otherwise not attacked; decomp. by fusion with alkaline carbonates and bisulphates. Occurs in almost all eruptives and Archæan rocks—in the former it is one of the first intratelluric crystals; abundant in granite, syenite, and gabbro; necessary in zircon-syenite.

51. Apatite. Hexagonal, columnar in eruptives, usually slender, but infrequently short and stout, granular, in crystalline schists massive.

H. 4.5 (massive), otherwise 5; Gr. 3.17–3.23. Luster vitreous–subvitreous. Color usually shades of green, sometimes variously colored; usually colorless by transmitted light. Transparent–opaque. Comp. $3Ca_3P_2O_8 + Ca(F,Cl)_2$. Rosenbusch says that all rocks contain apatite; more abundant in the granular eruptives and feldspathic crystalline schists of acid types.

THE ZEOLITES.

These form amygdaloids in the vesicular cavities of effusives, and replace other minerals in compact states by metachemism. They are, therefore, all secondary minerals and of little importance as rock-formers. Analcime is the only one that gives its name to a rock. In some cases they furnish by their composition an idea of the components (chemical) of a compact rock. They are all hydrous silicates of alumina with alkalies and alkaline earths, and can be divided into:

(*a*) Lime zeolites: Heulandite, epistilbite, laumontite (all monoclinic).

(*b*) Lime-soda zeolites: Stilbite (monoclinic) and chabazite (rhombohedral).

(*c*) Lime-potash zeolite: Phillipsite (monoclinic).

(*d*) Barium-potash zeolite: Harmotome (monoclinic).

(*e*) Soda zeolites: Analcite (isometric) and natrolite (orthorhombic).

Analcite generally shows the presence of nepheline or leucite, as it is altered from them.

The following species are found mostly in metamorphic rocks and crystalline schists. Some are found sparingly in eruptives; others never occur there. They are grouped according to their chemical composition.

SILICATES.

52. Scapolite (Wernerite). Irregular grains, fibrous, lath-shaped aggregates.

H. 5.5; Gr. 2.569–2.735. Luster vitreous-pearly to resinous. Color white gray bluish, greenish, reddish, all in light shades, but colorless and transparent when fresh. Fracture subconchoidal. Brittle.

Bp. Fus. easily with intumescence to a white blebby glass. Chem. Imperfectly decomposed by HCl. Occurs in metamorphic, but not primary, rocks.

53. Iolite (Cordierite). Orthorhombic, crystal, irregular grains.

H. 7–7.5; Gr. 2.60–2.66. Luster vitreous. Color shades of blue; colorless by transmitted light, rarely yellowish, blue, violet. Transparent–translucent. Comp. $H_2(Mg,Fe)_4Al_8Si_{10}O_{37}$.

Bp. Loses transparency and fusible 5–5.5. Chem. Partially decomposed by acids; decomposed by fusion with alkaline carbonates. Occurs most commonly in gneiss and the crystalline schists; less commonly in granite, quartz-porphyry, andesites.

54. **Garnet.** Isometric, crystal, granular-massive.

H. 6.9–7.5; Gr. 3.15–4.3. Luster vitreous to resinous. Color white to black through red, brown, yellow, green. Transparent to subtranslucent. Comp. an orthosilicate with interchangeable bivalent (Ca,Mg,Fe,Mn) and trivalent (Al,Fe,Cr,Ti) elements, as follows:

(*a*) *Grossularite* (Ca-Al-Garnet) (Cinnamon Stone).

Gr. 3.55–3.66. White, yellow, brown, red, green; colorless by transmitted light. Occurs in Archæan granular limestone and lime-silicate-hornstones.

(*b*) *Pyrope* (Mg-Al-Garnet) (Bohemiam Garnet).

Gr. 3.70–3.75. Red to nearly black; blood-red by transmitted light. Transparent and a gem. Occurs in peridotites and their derivatives.

(*c*) *Almandite* (Fe-Al-Garnet) (Oriental Garnet).

Gr. 3.9–4.2. Color red in precious garnet, black in the common variety; red by transmitted light. Occurs in granite rocks, andesites; most abundant in gneiss and Archæan rocks without feldspar.

(*d*) *Spessartite* (Mn-Al-Garnet).

Gr. 4–4.3. Color dark red, brownish red; by transmitted light blood-red, yellowish red, and colorless. Occurs in rhyolite.

(*e*) *Andradite* (Ca-Fe-Garnet) (Common Garnet, Black Garnet).

Gr. 3.8–3.9. Variously colored, but not white; brown by transmitted light. Occurs generally in metamorphic schists.

(*f*) *Uvarovite* (Ca-Cr-Garnet).

H. 7.5; Gr. 3.41–3.52. Color emerald-green. From the Ural Mountains, etc.

Bp. Fusible generally to a light-brown to black glass at 3 in (*a*), (*c*), (*d*), 3.5 in (*b*), and 6 in (*f*); most kinds react for Fe. Chem. All partially decomposed by acids; all, except (*f*), decomp. by HCl after ignition, and generally with sep-

aration of gelatinous silica; decomposed by fusion with alkaline carbonates. Plentiful in eruptives, but most common in metamorphic schists of all kinds, in serpentine, granular and crystalline limestones.

55. **Vesuvianite.** Tetragonal, in irregular shapes and prismatic aggregates, crystal only in granular limestone.

H. 6.5; Gr. 3.35–3.45. Luster vitreous to resinous. Color brown, green, seldom yellow; colorless by transmitted light, yellowish, reddish, seldom brown. Subtransparent to subtranslucent. Comp. a basic Ca-Al-silicate.

Bp. Fusible at 3 with intumescence to a greenish brownish glass; Fe with fluxes. Chem. Partly decomposed by HCl and completely after ignition. Occurs principally in metamorphic rocks; most common in limestones and silicate-hornstones in contact formations, less common in gneiss.

56. **Topaz.** Orthorhombic, crystal, rarely in grains or masses.

H. 8; Gr. 3.4–3.65. Luster vitreous. Color yellowish, white, grayish, greenish, bluish, reddish. Transparent to subtranslucent. Comp. $5(Al_2)SiO_4 + (Al_2)SiF_{10}$.

Bp. Infusible; in closed tube with previously fused microcosmic salt fuses and etches the glass for HF; blue on heating with cobalt solution. Chem. Partly attacked by HSO. Occurs in talc and mica-schists, tin-bearing granites and greisen. Alters to muscovite, steatite, kaolin.

57. **Andalusite** (Chiastolite). Orthorhombic, always crystal, seldom in grains, never massive.

H. 7.5; Gr. 3.16–3.20. Luster vitreous, often weak. Color red, gray, brown, green; by transmitted light usually colorless. Transparent to opaque, usually subtranslucent. Comp. Al_2SiO_5.

Bp. Infus.; gives blue (Al) on heating with cobalt solution. Chem. Undecomposed by acids, but decomposed by fusion with caustic alkalies and carbonates. Occurs in

metamorphic rocks and some contact formations; some forms are like sillimanite, and can only be distinguished by optical differences. Alters to mica, cyanite, kaolin.

58. Sillimanite (Fibrolite). Orthorhombic, long thin prismatic crystals.

H. 6–7; Gr. 3.25–3.34. Luster vitreous. Color brown green, grayish white. Transparent to translucent. Comp. like andalusite; also bp. Occurs in gneiss, mica-schist, and related crystalline rocks.

59. Cyanite (Disthene). Triclinic, columnar and parallel aggregates.

H. 5–7.25; Gr. 3.56–3.67 (the blue varieties are heavier than the white). Luster vitreous to pearly. Color white, blue (blue along the center of the blades and white on margins. Transparent to translucent. Comp. and bp. like last two. At high temperatures in the furnace is altered to sillimanite. Occurs in metamorphic and crystalline schists, almost universally with garnet. Alters to talc and steatite.

60. Tourmaline. Hemimorphic, rhombohedral, columnar crystal, rarely granular-massive.

H. 7–7.5; Gr. 2.98–3.20. Some varieties pyro-electric. Luster vitreous to resinous. Color black, blue, green, never white or colorless as a rock-former; by transmitted light always colored. Transparent to opaque. Comp. a silicate of Al, Bo, and either Fe, Mg, Na, or K.

Bp. Variously fusible, those with Mg easily so to a white blebby glass; with increase of Fe less easily so, and to a slag that darkens with the increased percentage of Fe; lithia varieties infusible; some react for Fe and Mn; give boric acid with bisulphate of potash and fluorite. Chem. Not decomposed by acids till after fusion, and then by H_2SO_4, and gelatinizes with HCl. Occurs in older granular and acid eruptives, rarely in later eruptives; alters to lepidolite, steatite, etc.

61. Staurolite. Orthorhombic, cruciform twins, prismatic crystals.

H. 7–7.5; Gr. 3.66–3.75. Luster subvitreous to resinous. Color shades on brown and black; by transmitted light yellowish-brown. Translucent–opaque. Comp. $HFeAl_5Si_2O_{13}$.

Bp. Infusible (Mg varieties fuse easily to black magnetic glass); reacts for Fe and sometimes Mn. Chem. Imperfectly decomposed by H_2SO_4; perfectly so by HF. Occurs in crystalline schists and in contact formations, never in eruptives. Alters to steatite.

PHOSPHATE.

62. Monazite. Monoclinic, small crystals.

H. 5–5.5; Gr. 4.9–5.3. Luster resinous. Color shades of red and brown. Subtransparent to subtranslucent. Comp. $(Ce,La,Di)PO_4$, with some Th. Bp. Infusible, turns gray and gives bluish-green color to the flame when moistened with HSO; with borax gives a bead yellow when hot and colorless when cool. Chem. Soluble with difficulty in HCl with white residue. Abundant in gneiss in Brazil, North Carolina; in large crystals in pegmatite dikes in Scandinavia and Finland.

OXIDES.

63. Corundum. Rhombohedral, also massive and granular.

H. 9; Gr. 3.9–4.16. Luster vitreous, sometimes pearly on basal planes; and sometimes showing a six-rayed opalescent star in the direction of the axis. Color black, blue, red, yellow, brown, gray, and nearly white. Streak uncolored. Transparent–translucent. Fracture conchoidal to uneven and splintery. When compact exceedingly tough. Comp. Al_2O_3. Occurs in three principal varieties:

(*a*) *Sapphire*, which is the general name for all pure

transparent to translucent states which are valuable as gems, and, according to color, are called red (true of oriental ruby), yellow (oriental topaz), green (oriental emerald), purple (oriental amethyst).

(*b*) *Corundum*, which includes the non-transparent and dark- or dull-colored states. It is ground and used as an abrasive and polisher.

(*c*) *Emery*, which includes the granular states of corundum which are black or dark-colored. It is an impure variety, as it is intimately mixed with magnetite and hematite, and is used for the same purposes as the last.

Bp. Unaltered; slowly dissolves in borax and salt of phosphorus to a clear glass, which is colorless when free from iron, but not changed by fusion with soda; a fine blue is given to the fine powder by heating with cobalt solution. Chem. Insoluble in acids; after fusion with potassium bisulphate or the similar soda salt is soluble, associated with metamorphic crystalline rocks, as crystalline limestones and schists, metagranite, etc. It is electric by friction.

64. **Magnetite.** Isometric, commonly in the octahedron and dodecahedron; one of the first-formed minerals in rocks.

H. 5.5–6.5; Gr. 4.9–5.2. Luster metallic–submetallic. Color iron-black. Streak black, except in some ores that are probably mixtures with hematite, and where there is the magnetic reaction with a more or less reddish streak. Opaque when in mass, but subtransparent when in folia of mica. Fracture subconchoidal. Brittle. Strongly magnetic; separated from pulverized rock mass by a weak magnet.

Bp. Fus. with diff.; in O.F. becomes non-magnetic; with fluxes is like hematite. Chem. Untouched by HF; easily sol. in HCl. As a rock it seems to be a varying mixture of protoxides and sesquioxides of iron, and its color and streak vary accordingly.

Weathering. Shows crust of earthy limonite with color yellowish brown.

It is the most widely distributed mineral in rocks, but occurs generally in small proportion and so minute as to be detected only by the magnet in rock powder; as an ore it exists in lenticular beds.

65. Chromite. Isometric, in octahedrons, generally massive.

H. 5.5; Gr. 4.32–4.8. Luster submetallic. Streak brown. Iron-black to brownish black; by transmitted light gray, lilac-gray. Opaque in mass. Fracture uneven. Brittle. Sometimes magnetic.

Bp. Inf. in O.F.; slightly rounded on edges in R.F. and becomes magnetic; with fluxes shows iron reaction when hot, but chrome-green when cold. Chem. Slightly touched by acids, but decomposed after fusion with alkali bisulphates.

Occurs in serpentine and in meteorites; never as an essential component of rocks.

CARBONATES.

66. Calcite. Rhombohedral, never in crystals; in irregular grains and plates.

H. 3; Gr. 2.71. Luster vitreous, subvitreous, resinous. Color white and variously colored. Transparent–opaque. Comp. $CaCO_3$.

Bp. Infus. and glows with reddish-yellow flame. Chem. Effervesces with cold HCl.

Occurs most extensively, after quartz, of all the minerals, as limestones, which will be treated later; also occurs in basic rocks as a filling of cracks, cavities, and amygdaloidal openings, and replaces silicates with pseudomorphs after them; also infiltrates from the country rocks of the mass. When limestone is metamorphosed it becomes "marble."

67. **Dolomite.** Rhombohedral, crystals saccharoidal with curved faces, grains.

H. 3.5–4; Gr. 2.8–2.9. Luster vitreo-pearly. Color white to black through reds, browns, greens, and grays. Transparent to translucent. Comp. $(Ca,Mg)CO_3$.

Bp. Generally like calcite, but does not, like it, give a clear mass with soda on platinum foil. Chem. Cold HCl acts slowly on fragments.

It occurs in sedimentary strata, which are sometimes altered from limestone through Mg solutions; also occurs locally in metamorphosed clay slates and phyllites; more frequently associated with magnesia rocks and minerals than calcite.

(The other minerals occurring as rocks will be treated later as economic products.)

The following are decomposition products:

Viridite is a greenish translucent form of matter in minute scales and fibres, which results from the decomposition of hornblende, pyroxene, and olivine.

Ferrite. Amorphous yellow, brown, or red earthy matter, frequently pseudomorphous after minerals containing iron. Chemically it is anhydrous or hydrated sesquioxide of iron, and forms the coloring matter of porphyries and weathered porphyrites.

Opacite. A term applied to black opaque amorphous matter in granules, patches, or scales, which occurs in rocks containing magnetite, and which some authorities state to be composed of it.

GENERAL DEFINITIONS.

Minerals occur in rocks in various (*M*) forms, as shown in the preceding pages. From them we see that two general forms occur in mineral matter — ***individualized***, when it is bounded by surfaces that can be readily distinguished (*M*) or (*m*), and ***unindividualized***, when it forms an amorphous mass or occurs in patches between individualized matter.

Individualized forms are:

(*a*) More or less perfect crystals, the failure in perfecting the shape being due to want of material or stoppage of crystallization, rather than to interference from other forces, as:

1. Perfect crystals with regular terminations.

2. Prismatic shapes with unterminated ends, which may be solid, fibrous, lath-shaped, columnar, or a mere shell filled with other minerals.

3. Solid pyramidal heads with prismatic faces more or less complete, or merely sketched by a few fibres, like the teeth of a comb.

4. What may be styled the unterminated skeletons of crystals, with only portions of the prismatic faces developed in irregular patches, and of the most minute thinness, which disappear entirely in places and leave only a tendency to break from the enclosing body along those (missing) faces.

(*b*) Crystalline grains which have an internal crystalloid structure (as shown by polarized light), but whose exterior presents irregular shapes due to interferences in crystallization, or to fracture or abrasion.

Unindividualized forms are:

(*a*) Vitreous particles or masses due to fusion and sudden cooling.

(*b*) Colloid masses, lithoid, stony.

(*c*) Aggregations of indefinite form, belonging to none of the above, and occurring in streaks, stains, tufts, etc.

Lithology on a megascopic basis requires that classifications and definitions conform closely to observations with the eye and lens; and the microscope must be left for theories of rock-formation. In the following pages association in nature (geological), mineral and physical states will be employed in forming divisions and groups, and bulk analyses used only as checks. The physical states are used in definitions of texture and structure.

TEXTURE.

This refers to the size, shape, state, and mode of union of the individual particles of a rock, whether they be single minerals, aggregates of minerals, or fragments of an older rock. In each case the texture definition must give the external and internal condition of those particles. These conditions are *characteristic* or *irregular*. The former are peculiar to free crystallization in a saturated solution; the latter to any other mode of formation, as (*a*) crystallization under other conditions than those above given, or (*b*) to organic or other mode of aggregation.

The divisions of texture are:

(*A*) *When some* (hypophaneromeric) *or all of* (phaneromeric) *the particles can be distinguished by the eye or the lens.* The varieties are:

I. **Crystal,** when both internal and external arrangement are characteristic. This is the "automorph" of Rohrbach, and the "idiomorph" of Rosenbusch. The latter, though the later, term is the better, as it means "characteristic," while the former is "natural." The converse of this is the

"xenomorph" of Rohrbach, and "allotriomorph" of Rosenbusch, and here the latter term is again the better, as the former is "foreign," while the latter is "peculiar to another," and the crystallization of many minerals simultaneously imposes on each forms peculiar to the bounding planes of those adjacent. Rocks cannot be formed wholly of crystals, and the term "holocrystalline" of Rosenbusch means "wholly crystalline-granular," and will be so used hereafter; but it might be forced from this sense to mean "wholly crystal (*M*)," where a rock has sufficient base to form an exceedingly fine-grained porphyry of its groundmass. There must, therefore, be a cementing medium when minerals occur crystal, and they so occur in three forms:

(*a*) Individual crystals ("phenocrysts" of Iddings), or fragments of crystals scattered through a groundmass to form a *porphyroid* texture or a *porphyry*. According to J. D. Dana the rock is "quartzophyric," "plagiophyric," "leucitophyric," etc, as the phenocrysts are quartz, etc. The *groundmass* may be divided (Iddings) into:

1. *Anisotropic*, or not of uniform constitution, when it is a holocrystalline mixture with particles of different sizes, which is Vogelsang's *granophyre* (if microscopic); or a mixture of phenocrysts in an isotropic base.

2. *Isotropic*, or the reverse of the former, when the microscope shows only amorphous matter, which is Vogelsang's *felsophyre* (when felsitic) and *vitrophyre* (when glass).

The late Dr. G. H. Williams divides the *holocrystalline* groundmass into one:

(*α*) Wholly composed of individual crystalline grains, or *microgranitic*.

(*β*) Where two minerals crystallized simultaneously and with equal rapidity, so that they became equidimensional and mutually interpenetrant, or *micropegmatitic* (see "Implication Structure").

(*γ*) Where a single large crystal or one of the two components of the groundmass may be filled with smaller and irregular grains or crystals of the latter, he suggests the term *poikilitic*, and, when microscopic, *micropoikilitic*.

Rosenbusch calls all crystals formed in the fluid magma in the hot abysses *intratelluric*, and many authorities state that the porphyroid texture is peculiar to such a crystallization, while Judd, Van Hise, and others have shown that some have been caused by secondary growths about crystals after solidification.

(*b*) As phenocrysts distributed through a crystalline-granular foliated mass, as in the metamorphic schists, to form *porphyritic* states of those rocks.

(*c*) As the result of "crystallinic metamorphism" (J. D. Dana), where crystals have been built up by infiltrating solutions, as just described.

II. **Granular,** when either internal or external arrangement, or both, are not characteristic. We can distinguish two varieties of internal arrangement—characteristic, or *crystalloid*, as in crystals (and apparent by polarized light), and *amorphous*, as in organic formations; guano, shells, etc.

We can also distinguish three varieties in external form:

(*a*) *Crystalline*, where the internal arrangement is crystalloid, but the external form is irregular, owing to an interference in the crystallizing of the components through their mutually constricting the areas in which they formed, as where crystallization is simultaneous in a solution of two or more minerals, and the particles are bounded by irregular and few faces whose shapes depend, not on the character of the mineral, but on the shape of the area in which it formed. This variety is found in massive and highly metamorphic rocks, and is usually preceded by an adjective to give the size of the components, as *phanerocrystalline*, where they can be detected by the eye, and *cryptocrystalline*, when

they cannot be resolved even by the highest power of the microscope, but where the glistening of the minute cleavage faces in incident light shows a crystalline texture. Under phanerocrystalline we distinguish coarse-, medium-, fine-, and micro-crystalline. The last cannot be resolved by the lens, but exhibits the glistening noted under cryptocrystalline. Medium-crystalline is so peculiar to granites that it called *granitoid*, and, if the rock is drusy, *miarolitic*. The form of crystalline grains can be readily seen by washing a thoroughly kaolinized granite till the quartz is clean. As quartz is the last to crystallize in granite, it is forced to accommodate itself to the interstices between the already formed feldspar and mica, and most highly shows the peculiar outline called "crystalline." Holocrystalline rocks, therefore, have their components crystallized into one another without the aid of a cementing medium.

(*b*) *Clastic* (Greek, "broken in pieces"), where the internal arrangement of the particles may be crystalloid or amorphous, but where the external form — whether in individual minerals or pieces of older rocks — is produced by fractured surfaces, or by faces (crystal or irregular) more or less worn by mechanical or chemical agents. Naumann called classes larger than a hazel nut *psephites*, sand sizes, *psammites*, and slime sizes, *pelites*. Clastics are always secondary and derivative, and their components may have an *angular* or a *rounded* outline — the former being the result of fracture; the latter, the modified form after transportation and weathering. Angular particles are called *sharp*, as a "sharp sand," which, when solidified, forms a rock of rough feel and is called a *grit*. Angular particles become rounded by mechanical agents, as moving water (rolled) or moving ice (glaciated); by chemical agents in weathering (etched). On breaking clastics there is not that showing of cleavage faces as in crystalline rocks, — even if the grains

are crystalloid, — as the particles are not crystallized into one another. They are, on the contrary, more or less dull on the surface, and are cemented together so loosely that the fracture extends around the particles instead of across them, and the surface exhibits only the combined dull surfaces of the particles in a very characteristic manner. When the cementing medium is of the same mineral as the rock, incipient metamorphism may produce something like the crystalline fracture. Similar comparatives are prefixed to clastic as to crystalline to denote the sizes of the grains—microclastic, for example. "Pyroclastic" is applied to fragments of the walls of dikes or volcanic vents which have been broken by the earth-throes, or by the abrasion of the intruding fluid.

Psephites are called *agglomerates* when the fragments are huge and heaped together disorderly, as by the caving in of the top of a cavern in a limestone formation, or the filling of the vent of a volcano by the fallen sides; *breccias* when all the fragments are angular. Through variations in the cementing medium we distinguish *pyroclastic-breccias*, where fragments of the country rock have been cemented by the erupted mass; *oroclastic-breccias*, where the grinding of the walls of the fissure on one another has filled it with their fragments, which have been cemented by intruding solutions of vein material; or, as in the Siluro-Cambrian limestone of eastern Pennsylvania, orogenic forces have extensively crushed the formation, but not displaced it, and infiltrating waters have cemented its fragments in almost their original positions. To this formation the term *brecciated* is applied, and *ordinary breccias*, where cliffs have scaled from aerial changes, and their fragments have been cemented. When the fragments are a mixture of angular and rolled shapes, it is called *brecciated conglomerate*, and when entirely rolled, a *conglomerate*. If some rolled portions of greater size than the average are scattered through the mass, the rock

becomes a *pudding-stone*. These terms alone do not form sufficient distinction for rocks, so that we must call them after the rocks from which they originated, as "quartz-breccia," "quartz-conglomerate," "diorite-conglomerate," "clay-slate-diorite-breccia." Very coarse conglomerate is called *shingle* when the fragments are larger than a man's fist, and have been formed by the grinding action of water on hard crystalline rocks. There is a class of formations that includes all sizes from the finest silt to blocks as large as a house, and which occur in generally unstratified aggregates, to form *till*, *moraine-stuff*, *bowlder-clay*, etc. These are due to glaciers with or without the concurrent action of moving water, and will be more fully defined later. The varieties of psammites and pelites will be similarly explained.

(*c*) *Irregular*, where both internal and external arrangement are amorphous, as in peat, guano, and similar rocks of organic origin. The phosphate rocks may consist of coralline limestones underlying guano beds, and into which the aerial waters have carried the soluble portions of the guano. This metachemized rock is also called "guano." Or, in the Tertiary aggregates of bones of land and marine animals, common to the coast regions of the southern Atlantic States, we have a peculiar formation, also found in the floor deposits of some caverns, and called *bone-breccia*.

(*B*) *Cryptomeric, when none of the particles can be distinguished.* There are two varieties of this:

1. When they are fused together in an amorphous mass; it is *vitreous* or *glassy*, when it has a texture and luster like glass, as in obsidian; *resinous*, when, with similar texture, the luster is like resin, as in pitchstone; *horny*, *flinty*, when homogeneous, cryptocrystalline, and with waxy luster, as in jasper and flint; *lithoid* or *stony*, with similar texture and wanting luster. This commonly is the result of "devitrification," or the conversion of a vitreous into a crystalline texture.

2. When they adhere loosely without fusion, it is *compact*, when dull, firm, and homogeneous; *earthy*, when composed of loose, friable particles; *plastic*, common to the pelites, capable of being moulded, formed, or modelled; *pulverulent*, when the compound is so fine and loosely cemented that it can be converted to dust by pressing between the fingers; *incoherent*, when it is still more loosely held together, and loses its shape by a slight shock or a puff of air.

Devitrification. This is a changing of a vitreous to a crystalline texture by means not well known. It is seen in the case of pitchstone dikes whose centres are glass while the selvages are quartz-porphyry. The felsites of Wales are shown to be pitchstones devitrified on an enormous scale, and similar widespread changes have taken place in the ancient rhyolites of the South Mountain on the borders of Pennsylvania and Maryland. Devitrification is shown by the formation of microliths, crystalline granules, or crystals which finally produce felsitic textures, so that the fluxion structures, lithophysæ, etc., are all that remain to testify to its original state. Some authorities go so far as to say that the quartz-porphyries, felsites, etc., are only devitrified forms of old extrusive glasses.

STRUCTURE.

This refers to the form—external or internal—in which the rock is massed. Internal structure generally has no effect on the external shape. Some structures can be seen only in terranes, others are exhibited in hand specimens, while a third class are revealed only by the microscope. Before describing them some of their causes will be briefly outlined, such as pressure, cooling, drying, solution, weathering, sedimentation, abrasion, impregnation, secretion, and convergence.

Causes of Structural Variations.

Pressure. The effects of pressure depend on whether it be applied to a homogeneous and equally resisting mass, or to one with portions varying in resistance to deformation, whether the mass be plastic or solid, and whether the mass may be displaced as a whole by the pressure or not. Tyndall has shown that pressure applied to a homogeneous mass without power of motion along the direction of the force will produce a tendency to split into parallel plates whose planes are at right angles to the direction of pressure. These planes are called *cleavage-planes* in fine-grained masses, and some varieties of *foliations* result in coarser masses from the same source. In case the mass be solid and the pressure produces a warping or torsion, a series of fractures relatively parallel to one another occur, and these are crossed by a second series making slight variations from a right angle with the first set. These are *joints*. With unequal resistance to deformation certain portions of the mass move through greater distances than adjacent portions, and *shears* result. The fractures thus formed may be slight or of vast dimensions. In a sedimentary mass the gradual weighting of the overlying portions exerts an increasing pressure on the lower parts, and if these are locally of varying degrees of resistance, the stronger parts will retain their form and project into the softer overlying parts, that sink around them, as shown by Marsh in the case of *stylolites*. With a greater solidity to the mass the grinding of the sides of the fracture on each other will produce groovings and polishing. In the gneiss of the South Mountain, in Pennsylvania, an abundance of minute *slickensides* occur from this cause where the relative area of fracture is but a few square inches. Pressure applied to the edges of a mass that has freedom for bending will produce two series of fractures at right angles to one

another. The first series are parallel to the axis of the cylinder or cylindroid formed by the mass, and radial, and are caused by the stretching of the upper layers of the mass. The second series are caused by inequality in resistance to the pressure, as above stated, and the shears produce fractures parallel to the direction of pressure. The latter is the ordinary cause of *faults*, with extensive movement of the walls up and down, as shown in slickensides of great areas. The two series of fractures can be beautifully seen in the hard slate partings of the sharply flexed beds of anthracite in this State.

Cooling. On cooling a molten mass against a plane surface strains are developed that cause symmetrical fractures to extend normal to that surface, and divide the mass into prisms with polygonal section. In a dike the walls are cooling surfaces, and the prisms run across the dike-opening; in a surface sheet the prisms are vertical; in either case the axis of the prisms is *normal to the plane of flow.* Owing to the quicker cooling of the part near the walls, secondary fractures are caused parallel to them, so that the prisms are divided by planes parallel to the base. (See further under "Weathering.")

Drying. In sands and muds a variety of structures are produced by *surface* and *internal* drying. Surface drying produces two series of cracks at right angles to one another. The former are due to the shrinkage of the mass, and extend into it normally to the drying surface, as can be seen in any mud flat exposed to the sun and air, in the form of polygonal prisms, much like those caused by cooling, but irregular in outline; the latter are due to the more rapid drying of the upper layer of the mass, and a corresponding shear, that separates that layer from the next and causes it to curl upwards where this fracture meets the prisms. This latter form is seen in the greater readiness of masses of plaster of Paris or artificial stone solidified in uncovered boxes to

fracture parallel to the drying surface more readily than across it.

Internal drying takes place in pelitic masses that are exposed to loss of moisture on several sides. The exterior on drying becomes rigid, and the moisture of the interior passes through it without influencing the shape; but the loss of moisture makes the enclosed portion shrink away from the dry shell. The new surface of the latter may dry in a similar manner, and have a second shell formed. The so-called "rattle-stones" in clay are formed in this way. A second type of centripetal drying forms the concentric rings of staining (J. D. Dana) seen in breaking sedimentary masses.

Solution. The passage of waters through the earth's crust, with or without acids in solution, dissolves portions of the crust along the lines of flow, and *etches* the surfaces over which they pass, or excavates caverns of varying dimensions. Limestones are the best examples of rocks thus affected, and the great caves of the world are in this rock. (See further under the next topic.)

Weathering. The weathering of rocks depends on their mineralogical composition and mode of aggregation, and comprises those changes in shape and character due to exposure to the "weather," i.e., to the atmospheric agents, taken in their most extended sense. These are the mechanical and chemical effects of the air (wind, rain, humidity, variations in temperature, frost, and the chemical solvents) and the humic forces (mechanical effects of growing vegetation and the acids of the soil). The result is the reduction of solids to a friable, sectile, or plastic state by the removal of soluble ingredients; or the formation of carbonates, oxides, or haloids. Under the first case a granite becomes a crumbly mass of quartz fragments imbedded in kaolin, which may be white, or stained with iron from whatever ferruginous bisilicate formed the essential mineral; a trachytic porphyry kaolinizes to a compact and sectile tuff, and a clay slate

turns to a bed of clay. Under the second case an outcrop of argentiferous galena changes to carbonate, or to horn silver; while the well known "iron hat" forms on a pyritiferous lode. A rock can frequently be determined by weathering alone when there is a great and well-marked difference between the fresh and weathered states—especially if it be a non-fossiliferous part of a generally fossiliferous formation. The rolled cobbles of Oriskany sandstone in eastern Pennsylvania take a high polish and a deep red, the latter from the oxidation of the minute portions of iron in the mass, which give the fresh rock a slight tinge, as can be seen on breaking a bowlder, whose interior is whitish and gritty. Ferruginous rocks highly oxidized on the surface are bleached when covered by peat bogs, while, on the contrary, white quartz pebbles are deeply and irregularly stained by immersion in ferruginous muds, as are the pebbles of Potsdam quartzite in Triassic conglomerate in eastern Pennsylvania. A limestone that appears compact and non-fossiliferous on a fresh fracture may be found to be highly fossiliferous if we examine the etched fragments in the weathered talus, where the less soluble fossils stand in high relief. Weathering, therefore, affects the hardness, color, and composition of a rock, or all of them, and the student should become familiar with the various states. Some rocks are exceptions and harden on weathering, as do sinters, some sandstones, and the shell aggregate of Florida, called *coquina*, owing to the hardening of the cementing medium through drying. Weathering acts more rapidly along than across bedding planes, and frequently reveals the bedding in an apparently unstratified mass. Weathering also shapes masses by removing more rapidly the sharp angles, and reducing the mass to a spheroid (spheroidal weathering). The fracture of a spheroid discloses a series of concentric shells that approximate in composition from the fresh nucleus to the highly oxidized exterior. Spheroidal weathering also takes

place in rocks with no soluble ingredients, as in the Potsdam quartzite of eastern Pennsylvania. Here it is due to sudden alterations in temperature from rain-squalls on a hot day. The effects of sudden cooling can best be studied on the sea-shore in the northern part of the temperate zone during the summer, where there is an abundance of bowlders of eruptive rocks. These become intensely heated during low tide, and give low cracking sounds when first struck by the returning waves. Cold showers have a slighter effect. This is accompanied by alteration of the minerals through the changes mentioned above. This variety of weathering seems to be greater in a composition of highly basic anisometric minerals, owing, perhaps, to the inequality of strain in the heated part, and the sudden and unequal contraction in cooling, which, in many cases, produces flaking, and may be the cause of the decay of the Egyptian obelisks since their removal from that country, as they remained there intact for centuries, whether in the air, or half buried in the bitter brines with which the soil is saturated, but have deteriorated when removed from a climate of uniform temperature to those of great and sudden variation. Joints, fractures, cleavages, and bedding planes aid weathering, and the depth of weathering depends on the relative progress of formation and removal of the decomposed part, and varies with latitude and location. Weathering, finally, is a variety of metachemism.

Sedimentation. This is the deposit by and under water of the worn material from weathered rocks. If the deposition is continuous and the material uniform in size, there will be formed a mass of uniform character when viewed on a section made in any direction. Moving water has a sorting power, and Hopkins has shown that this varies with the sixth power of the velocity. During the spring and fall freshets the rivers are carrying a burden of larger sizes than during the low waters of summer and winter. Sediments thus formed will

show coarser and finer layers intermixed. Leconte has summed the conditions for this intermixing of layers, called *stratification*, as follows: for stratification in still water (a lake or the ocean) there must be a heterogeneous supply and an intermittent cause, while for running water there must be in addition a variable current. If the strata are formed of different *compositions*, as sand, clay, calcareous mud, etc., they are called *beds* of sand, clay, etc. Sedimentary formations are called *bedded*, and the planes or surfaces that separate adjacent beds are *bedding planes*, etc. A section of stratified rocks generally shows a variation in size, kind, or color of material, or all of them, and such rocks tend to split more readily along than across the bedding planes, while penetrating solutions enter more easily along than across the same, even though the mass be fine grained, as in the pelites, and the stratification planes are not apparent. The variations in structures will be noted later.

Abrasion is a rounding of the surfaces of rocks by contact with other rocks moved by air or water. The winds carry fine sands, and sculpture and polish the rock faces exposed to their action, as is seen in the Western States, in Egypt, and along sea-coasts. From a study of the etched windows along the New Jersey coast the "sand-blast" was devised, by which stones of any hardness are cut to any shape required, pierced, and otherwise worked. The prime motor in abrasion is water, liquid or frozen. Rocks in river bottoms are rounded by what is dragged over them. Rapidly moving water in torrents or waves rolls fragments together as in a barrel and rounds them by mutual attrition. Glaciers round the surfaces of hard rocks over which they flow and form "sheep-backs," "whale-backs," etc., while the fragments that do the work are themselves more or less rounded. Water-rounding by strong currents is called *rolling*, ice action, *glaciation*.

Impregnation. This is due to thermal waters or vapors

acting along certain planes in a mass, and introducing foreign elements to form new mineral combinations. The first case is where a solid porous rock is fractured, and along the fracture comes thermal water or vapor to penetrate the pores for a limited distance from the fracture, and leave therein the substances held by the solution or vapor. The second case is where the same agents are injected into a fluid mass, or, with such a mass, into a fissure, and produce the given effect on a limited portion of the same, as boric and fluoric acids are thought to have produced the veins of greisen in granite. Geikie and other authorities call these last *segregations.*

Secretion. This is a leaching of portions of a mass by penetrating waters or vapors. The simplest case is when carbonated waters dissolve portions of limestone in passing through, and are forced to deposit the same, whenever they lose their free acid, as stalagmite, stalactite, travertine, etc. In the case of thermal waters they dissolve silica, if alkaline, and deposit the same on cooling or drying, to form sinter. Thermal waters or vapors are thought to be agents in the formation of some "veins," by secreting portions from the country rocks, and depositing them in fissures or cavities in the same. Geodes, amygdaloids, etc., are similarly formed.

Convergence. There are a number of more or less similar rock structures that are due to the convergence of similar molecular compounds; but what initiates the convergence, or whence and why the molecules converge, is unknown. On assembling the structures it is found that they can be grouped according to whether the convergence was free or restrained. The molecular compounds may exist in solution, in a fused magma, or in vapor.

(*a*) *Free Convergence.* This is shown in all forms of crystallization where there was freedom of growth in one or more directions, as :

1. Crystallization from a solution or fluid magma, where the forms would be characteristic.

2. Segregation, or crystallization in non-vesicular openings in solid rock, as in *veins* and *geodes*, and from solutions or vapors.

3. Vesicular crystallization, in states of extrusive rocks in such proximity to the surface that the occluded steam could expand, but not escape. This occurs in rocks of the highest acidity (rhyolites) as *lithophysæ*, and in basic rocks under two forms—with acid solutions, as calcite, zeolites, etc.; with alkaline solutions, as crystalline quartz in geodes, or colloid agate or chalcedony.

4. Sedimentary crystallization, when single crystals or crystal aggregates form in fine sediments, from the intrusion of saturated solutions, accompanied by some unknown force, as pyrite in clay, and in shales of the coal region, and possibly both are due to the same cause. In the latter case it is the reducing action of the organic aggregate. Fontainebleau limestone is another example of this class; also dendritic magnetite, etc.

(*b*) *Restrained Convergence.* This is commonly known as *concretion.* The texture of concretions may be crystalline or colloid; the force may act towards or from the centre, and the form will vary with the amount of restraint opposed by the mass in which the concretion forms to the entry of the molecular compounds. If the restraint is equal in all directions, the concretion is isometric; if unequal, as in sediments (especially if of varying strata), anisometric. Under this we find:

1. Crystallizations from a pasty magma, or simultaneous crystallization of varying compounds, to produce fibrous, columnar, lath-shaped aggregates.

2. The aggregation of mineral matter in non-crystalline

form in an otherwise crystalline mass, as the nodules of mica in some granites and gneisses.

3. The same aggregation in a suddenly cooled mass to form spherulites, axiolites, etc.

4. The results of devitrification, as microliths, etc., perlitic structure, etc.

5. Ordinary concretions, which may be spherical, lenticular, botryoidal, tuberous, pipe-formed, etc.

External Structure.

This may be symmetrical to an axis, as columnar, stalactitic, filiform; to a plane, as jointed, stalagmitic; centric, as spheroidal; and irregular, as etched, rolled, glaciated, concretionary. The last two may have any or all of the symmetrical forms.

Columnar. This is peculiar to dike and sheet effusions, and is due to cooling (see *ante*). A slight columnar structure is also caused in pelites by drying (see *ante*). In both cases the columns are normal to the cooling or drying surface. Basalt shows the structure more commonly than other effusives, though it is seen in phonolite and obsidian with distinctness. This is called "jointing" by some authorities, and distinguished from the ordinary kind by the adjective "basaltic." In some cases only one series of fractures is developed, so that the masses are tabular. In other cases the opposite holds, and so great a number of cracks are formed that the columns are roughly cylindrical. These are generally divided by the fracture parallel to the walls, before described, into rhomboidal, cuboidal, or prismatic pieces—in case the fracture be plane; but, if irregular, it causes them to break in pieces with "ball and socket" form, and frequently with spheroidal form.

Stylolitic. O. C. Marsh has shown that these are due to pressure, from the "slickensided" appearance of their sur-

faces. They are columnar or cylindrical bodies varying from a fraction of an inch in length and breadth up to four inches in length and two inches in diameter, and are found at right angles to the bedding of the mass (limestone or marl), and are composed of the same material.

Cone in Cone. The same author suggests a similar origin for these structures which extend through thin beds of limestone or calcareous shale in the form of cones. They may have been formed by pressure on concretions in process of formation (see *ante* under "Pressure.")

Stalactitic. Solutions formed by percolating waters usually find certain lines of flow less obstructed than others, and the streams or drops fall more frequently where these lines meet the surfaces of cavities in the mass, and deposit there portions of the material in solution; so that in time a formation similar to an icicle extends from the roof, and may become many inches, or even tens of feet, in length. Stalactites are common in limestone caves, under arches of masonry (from the stone, or even the mortar), under troughs through which mineral waters flow, and may consist of calcite, fluorite, limonite, or other soluble mineral. They are variously colored and frequently show a colored banding on a transverse fracture.

Filiform. This is seen when glass tubing is heated and pulled apart, or when artificial mineral wool is formed by forcing air through slag. It occurs in nature under similar conditions when highly fluid lava is drawn out by being blown into the air, or drawn out by wind, to form what the Hawaiians call "Pele's hair." Pele was the goddess of the nether world.

Jointed. This is a tendency to separate into massive sheets with parallel bounding planes, and is generally due to warping or torsion (see *ante* under "Pressure"). A columnar structure is commonly formed by the intersection

of two sets of joint planes; but the columns can be told from those formed from cooling or drying by the fact that joint columns are four-sided and frequently square on a section, while the others are polygonal. While jointing is usually on a large scale and forms the external shape of masses, it is frequently so minute as to become internal, and so frequently repeated as to resemble cleavage. Jointing is not always apparent in fresh states of rock, but shows only on weathering. This variety is called *blind jointing* by miners, and is used by them in "breaking down" masses. Jointing is also called *cleat*, and frequently, as in some coals and ores, when there are two systems of joints at right angles to one another, the system that is more developed, and allows the mass to separate more readily, is called the *face* of the ore, while the other system is the *end*. Workings are driven against the cleat or face. A good example of jointing in metamorphic rock is seen in the gneiss of Port Deposit, Md., where the mass is divided into layers of great evenness, and varying from a few inches to many feet in thickness. Where there are two systems of joints in stratified rock, one is generally parallel to the dip (dip-joint) and the other to the strike (strike-joint).

Spheroidal. Under "Weathering" it was shown how angular masses lost their sharp corners and acquired a rounded outline. This is *spheroidal weathering*. The same shape is seen in fresh volcanic products when the explosive action throws portions of the molten mass into the air with a rotary motion, and they solidify under this condition, to form volcanic *bombs*. The beginning of spheroidal weathering produces a *subangular* shape.

Etched. The surface of soluble rocks is rounded by the passage of solutions over them, and this is most commonly shown by the action of water in flowing through jointed

limestone, as the angular masses are rounded and the joints widened into fissures and caverns.

Rolled. We can distinguish current- and wave-rolling. Current-rolling takes place in rivers that have periodic currents of great depth and velocity, and intercalated periods of low water and weak currents. During the former the burden of trash is dragged over all stones too large to be moved, and smaller sizes roll along. The small stones and sand are whirled over the bottom so as to reach all sides of the fixed stones, and the hollows are as finely polished as the projections, the sharp contours only being rounded off in hard rocks. The smaller stones take a shape dependent on their hardness and habit of fracture. During the low waters and weak currents, which prevail during the greater part of the year, all sorts lie on the river bottom and weather, so that river pebbles vary in character, being most rounded and polished in torrential streams, and furthest distributed from their original bed. In sluggish streams with no rapid currents there is little distribution and angular material: the river bed representing the adjacent rocks, while the average river pebbles have a rough and pitted surface. Wave-rolling is seen on steep beaches, where, in a storm, the grinding of the shingle under wave action furnishes a large component of the noise. Under this intense attrition the friable rocks fall to sand, and only the hardest remain to be finely polished. The wrecking of a Philadelphia collier off Nantasket Beach, some years ago, furnished a supply of anthracite coal in shingle and sand, but it wore away to powder in a few months.

Glaciated. The abrasion is entirely between the exposed surface and material carried by the ice. Surface glaciation takes shapes dependent upon the kind of rock and the manner of fracturing. In a hard rock that exhibits jointing the surface is rounded to form the "sheep-backs" and "whale-

backs" shown in works on the subject. This is after the old surface soil due to the long period of weathering that preceded the ice advance had been removed, and the solid interiors of the masses between joint planes came under the planing action of the glacier, and resisted it better than did the less solid portions along those planes. Softer shales are cut down to a flat surface if the material in the ice is of uniform size; but larger and harder fragments show their presence by deep striations. The ice advance over a non-glaciated region has neither hard rock surface to act upon nor hard material to drag along, so that there may be *planing* at a distance back from the ice front, but no *striation.* The material carried by the ice is rounded only on those sides exposed to abrasion against the surface; other sides retain their angularity. The masses carried over a hard bottom show scratches arranged in sets of parallel lines, depending on the variety of ways they were held by the ice.

Glacial aggregation. This can generally be distinguished from sedimentation by the absence of stratification in the mass, and by the heterogeneous mixture of the finest clays with bowlders of the largest size without the slightest trace of sorting. Where the glacier dams a valley and forms a lake a peculiar form of sedimentation occurs—the peculiarity being due to floating ice. In the still water the finest sediments are distributed to form a more or less sandy clay, and, from the continuity of deposition and uniformity of deposit, there is no stratification. This would not be very noticeable were it not for the bergs "calved" from the ice front, which sail out into the lake bearing their burden of angular and glaciated material, which is dropped on melting and falls to the bottom, to become imbedded in the clay. The rounded pieces drop in straight lines, but the flat and unequiaxial pieces fall along lines of least resistance from

the water and enter the mud at all angles. In case the deposit were formed by ice alone on a glaciated surface, the pressure would arrange these with longer axes parallel to the movement. An unstratified clay carrying angular and striated or glaciated material arranged in an irregular manner through it has been formed in slack water, and the large burden has been distributed by ice. In the event of the second advance of ice over a previous glacial deposit, there is sometimes a pushing and distortion of the old surface, and not its entire removal.

Concretionary. The structures under this head have a common convergent origin, but take a variety of shapes, which depend on the ease of access of the solution to the origin of the concretion, and growth to or from that origin. Following J. D. Dana, we can divide concretions into centripetal and centrifugal; and as the origin is a point, a line, or a plane, the structure may be *centric*, *axial*, *flat*, or *irregular* (if it be wholly anisometric). The texture may be crystalline, colloid, or earthy. The growth may be continuous or intermittent; of considerable size, so as to separate masses, or so minute as to fall under internal structure. We can distinguish concretions

(*a*) From a solution. These are centrifugal, and are due to the grouping of molecules from the solution about some nucleus. They are seen under process of formation in the waters from the Carlsbad springs. A section shows a small grain of sand or speck of some foreign body as a nucleus, which was rolled about gently by the waters and coated concentrically with "sprudelstein." When a mass is built up of minute spherules, its structure is *oölitic*, and when the spherules are as large as a pea, *pisolitic*.

(*b*) From an intrusion of a solution into a loose mass. The masses are usually alluvial clays, marls, chalk, and even loam. As these are sediments and usually stratified, there

will be a greater freedom of motion of the solution along bedding planes than across them, and the growth will be greater parallel to the bedding than across it, so that flat concretions will form. An irregular variation in porosity will cause an irregular shape. Structures under this class will be spherical, lenticular, botryoidal, mammillary, reniform, tuberous, flat, and irregular. In clay we find clay-stones, eye-stones, spectacle-stones, imatra-stones, fairy-stones, where the solution bears calcite; nodules about pebbles, leaves, fish, etc., in the clays of the Carboniferous, where the solution contained both calcic and ferrous carbonates; amorphous nodules of pyrite in coal shales, where the ferrous sulphate in the solution was reduced by the organic matter in the clay, to form what miners call "bells," and which run from minute to large dimensions. In chalk we find flint nodules from the dissolved silica of sponges which has formed around other sponges or other siliceous formations. In loam we find calcite nodules which, in India, are called "kunkurs" ("nodules"), and which form in openings left by roots, or around small bodies, and furnish limestone in sufficient abundance for mortar. In guano and bone beds similar concretions of calcic phosphate are found. It sometimes happens that the concretionary mass has formed centripetally, and that the soft interior has shrunk away from the shell and cracked from drying. The open spaces are then filled with some mineral, usually calcite, and form *septaria*. If not so filled, they form *rattle-stones*. In highly ochreous clay the hydrated sesquioxide of iron takes various forms, and is called "bean ore" when of small size, "ore pots" when larger and hollow, "pipe ore" when in axial shapes. Limonite concretions form rapidly, as is shown by the finding of discarded spikes from the track in the center of concretions which, have formed at their expense.

(*c*) From a similar intrusion into a rock after its solidification. These can be distinguished from the former by the continuity of the bedding planes through the concretion. They are found in sandstones and shales from intrusions of solutions given above, and appear to be formed partly by the concretionary power of the solution, and partly by its drying, as stated under that topic.

Internal Structures.

These may be uniform and varied. The only uniform structure is called *massive*, the uniformity being local. It is possessed by primary rocks, and shows no divisions into strata (layers, beds). Primary rocks are frequently called *massives*. The varied structures may be regular and irregular. The latter are:

Damascened (Rutley), as in some obsidians, where the threads of glass are contorted in a confused manner like the markings on Damascus sword-blades.

Porous, where the rock is penetrated by irregular and often angular cavities, due to the removal of some of the minerals, or to the interstices left during the rock-formation; not due to gas. If the openings are large, it is *cavernous*.

Regularly Varied Structures. These may be (*a*) bounded by spherical surfaces, or (*b*) repetitions symmetrical to a plane, warped surface, straight or wavy line. The former will be called spherical, the latter parallel, structures.

(*a*) Spherical Structures.

Cellular. This term is applied to rocks containing cavities more or less rounded from the expansion of gas during effusion. They are generally quite spherical if the motion of the mass had stopped before it became so pasty as to resist the expanding force; if the contrary state existed, the structure will be described later. The

structure is most commonly met with in surface portions of compact effusives. If the cells are *few* and *isolated*, the state is called *vesicular;* if they occupy an equal space with the solid part, it is styled *scoriaceous*, or slaglike ; if the cavities predominate, *pumiceous*, or foamlike. When the cavities become filled with agate, calcite, or zeolites leached from the walls, the state is *amygdaloidal.* In obsidians similar cavities, called *lithophysæ* (v. Richthofen), are thought by J. D. Dana to have been filled with an aqueo-igneous or jellylike secretion, which, by alternate crystallization and drying, forms a series of concentric crystalline spheroids of solid or spongy character. The minute crystals are of quartz, tridymite, feldspar, topaz, and garnet.

Geodic, when cavities of any shape are lined with crystals, but not completely filled. In some cases layers of chalcedony occur under the crystalline layer. If the crystals are minute, the structure is *drusy.*

Spherulitic, Globuliferous, and *Spherophyric* (J. D. Dana). This is a concretionary structure found in eruptives, and is formed during the plasticity of the mass, as shown by the elongation of spherules by its motion. It occurs megascopic from concretions of mica, or feldspar and mica; or microscopic from the formation of spherulites which are radially crystalline. A not very common form of spherules is caused by the fusion of pyroclastic fragments of the country rock in the intrusive fluid. A good example is seen in the spheres of willemite in the dikes cutting the ore body in the New Jersey zinc mines.

Perlitic. This is characteristic of perlite, but is found in other vitreous rocks. During cooling the mass is fissured by minute cracks that form spheroids and ellipsoids, whose section shows concentric coats. This is held by some authors to be similar to the spheroidal jointing shown on a greater scale by basalt, etc.

(*b*) Parallel Structures.

Those symmetrical to planes and warped surfaces will be called *flat parallel;* those symmetrical to lines, *linear parallel.*

The flat-parallel structures are:

Bedded, Stratified. Stratification has been already described. We distinguish *seams,* or thin layers differing in character from those above or below; *beds,* as thick seams; *bedded masses,* when the horizontal dimensions are inconsiderable in comparison with the thickness; *lenticular masses,* when beds thin out and appear to be isolated in a stratified deposit. The varieties of bedding are:

Massive, when of great thickness, and not divisible into layers.

Straticulate (J. D. Dana), when made up of even and thin layers, separate or not, as in clay, stalagmite, agate, etc. It is also called *banded.*

False bedding (A. Geikie) includes all kinds that are formed otherwise than by distribution in still water, as:

(*a*) *Current-bedding,* where the stream pushes the detritus along irregularly, so that the front has a slope of 20°–35°, and the successive deposits are parallel to this slope. In an estuary the alternating slack waters deposit horizontal layers, so that regular and cross-bedded layers are intercalated.

(*b*) *Flow-and-plunge* structure exhibits a curved cross-bedding that is without intercalated regular bedding. It occurs where waves work over a supply of sand and fine gravel, and is seen on shores and sometimes in sub-glacial deposits.

(*c*) *Beach structure* is a similar case, but exhibits a variation in angle of bedding at the level of high tide. Above that the beach has a slight slope; below, a steeper one.

(*d*) *Wind-drift* structure is composed of straticulate

layers in positions oblique to one another. It is caused by variations in wind direction in a sandy region.

Trough-bedding (Ger. *Muldenförmig*), when sediment is deposited in a depression, and takes the shape of the same; but, owing to the slipping of the sediment down the slopes, the layers are thicker in the trough than on the sides, and, eventually, the depression is filled, and the overlying layers become horizontal. A good example is seen in the Mesozoic coal basins in Virginia, where the deposit is in hollows in the Archæan rocks.

Cloaklike Bedding (Ger. *Mantelförmig*), where a sinking of the surface causes a lake or ocean, and the hills and smaller elevations are gradually submerged or "cloaked" by the by the sediment. This is seen on a large scale in the bottom of Lake Bonneville, Lake Lehontan, etc. Here the strata dip in all directions from the submerged mass. This and trough-bedding must not be confounded with synclinals and anteclinals, which are caused by flexing beds originally horizontal and parallel, while the above were never horizontal, and always thicker at their lower than their upper parts.

Veined. A vein is a parallel and "comblike" arrangement of crystalline matter in an open fracture in older rocks. The crystals usually have their longer axes — especially in the vein matter — normal to the walls of the fracture. Alternations in the solutions cause variations in the minerals, and the layers are deposited on one another till they meet in the centre of the fracture. The parallel arrangement of vein matter is not like the similar arrangement of stratified matter, as in the first there is a repetition of the order of succession of the deposits on either side of the middle of the vein, while there is generally no symmetry in the stratification of a bed. The vein, also, is crystalline; the bed, clastic. The varieties of veins and their origin belong to economic geology. One of the most common vein-

formers is quartz, and it fills the small cracks in sandstones with material more dense than the rock, so that weathering brings them into relief.

Fissured, Fractured, where rocks have been deformed and crushed. In case the walls of the fissure have been moved on one another, the grinding forms *slickensides.* These may be grooved or plane. The soft shales of the coal frequently have been grooved; but their softness would have allowed the evidence to be lost were it not for the filling of the fissure with quartz, which has preserved a cast of the same with the minute groovings. In case the rocks are pyritiferous, the movement produces a plane surface with a mirror-like polish ; but weathering blackens the same without entirely destroying the lustre. In orogenic movements the rocks are sometimes finely crushed, and Bonney claims this as preliminary to one form of schistocity.

Fissile. This is a general term for a tendency in rocks to split more or less readily. We can distinguish

(*a*) *Shaly* (*Laminated*), where there is an arrangement in layers, relatively parallel, and a tendency to split along the layers. This is also called stratified, and fine layers are straticulate or *laminated.* The texture is generally fine, as in pelites.

(*b*) *Schistose* (*Foliated*), with the layers wavy through the somewhat parallel arrangement of unequiaxial minerals, or those that are eminently cleavable in one direction, as mica, talc, chlorite, hornblende, etc. The thin flakes are called *folia.* The texture of schists is crystalline, and coarser than the clastic, or crystalline-clastic texture of shales.

(*c*) *Slaty* (*Cleaved*), with a tendency to split in thin sheets parallel to a given plane, and with a fine and homogeneous texture. It is produced by pressure, as before stated (p. 63), and is known, in coarse-grained rocks, as a species of jointing.

We distinguish the varieties of cleavage as follows: (1)

If parallel to the bedding, and in fine texture, it is generally *shaly lamination;* if in a coarse texture, *flagstone-* or *flagband-cleavage.* (2) If at an angle to the bedding, and in a fine texture, *slaty-cleavage.*

Streaked, Fluxion Structure (A. Geikie), *Banded* (Rutley), *Fluidal* (J. D. Dana). The term "streaked" is indefinite; "banded" is applied to other structures, as in agate, onyx, etc.; and neither affords information regarding the origin of the structure, which is peculiar to igneous rocks. Geikie defines it as "having some or all of the component minerals arranged in streaky lines, either parallel or convergent, and often undulating." (This last would include Rutley's "damascened"). He further states that it is found less marked in crystalline rocks, as diorite and dolerite. Dana defines it as "having the material of the rock or of portions of it in parallel lines or bands and looking as if due to the flow of the rock while melted." He further speaks of the "thin laminated structure" of trachytic and andesitic lavas as due to successive action in the supply of lava to the point of outflow, and refers to Iddings. There are a number of structures thus referred to "flow": (1) a banding of the rock in laminæ, as in the lavas above mentioned, and in "slaty" porphyry — this structure causes the rock to break a little more readily along than across the laminæ; (2) a stretching of the rock by the flow so as to show a structure like that in pulled molasses candy; (3) a stretching of vesicles in the line of flow, so that they are no longer spherical, but pear-shaped or elongated; (4) a fissuring or fracturing of phenocrysts by movements of a pasty matrix. The experiments of Tresca on "flow" in solids have been improved upon by Townsend, whose exhibits show on polished and etched sections the particles arranged along "fluxion" lines, as in the states of rocks just noted. While, therefore, it may be possible for this structure to be formed in solidified rocks,

it is generally exhibited in movements during a pasty state, though the fissured phenocrysts show that motion followed initial crystallization.

Linear-parallel structures:

The second and third varieties of the last structure are linear parallel, but cannot be well separated from the others. Also:

Fibrous, where some of the mineral components are composed of distinct fibres, as in gypsum, satin-spar, chrysotile, amianthus, asbestus, etc. Some concretions are fibrous, but they do not fall here, as they are convergent.

Lathy, where some or all of the components are in flat or twisted lath-shaped forms, as in some diabases, cyanite rock, etc.

Implication Structure, where there has been a peculiar and regular infolding of one another by two synchronously formed ingredients of a rock (Zirkel), as by the quartz and feldspar in pegmatite, where the quartz is systematically arranged on certain of the cleavage planes of the feldspar so as to produce characters that have been likened to Hebrew, Assyrian, etc., and the rock called *graphic granite*. The structure is also called *pegmatitic*.

A number of (*m*) structures are omitted here.

Fulgurite. The effect of lightning on the earth's surface is to fuse the rocks to varying depths and produce a natural glass therefrom, which is called fulgurite. In solid rocks this may be only a surface fusing, but in sands there is sometimes a tube of considerable length (up to ten feet) thus formed. Fulgurites are indicated by glassy patches, drops, or tubes on rocks, and are found most frequently on the tops of high peaks. In sand the tubes may be three inches across. This form of glass is distinguished by the absence of microlites, thus showing its sudden cooling.

COMPOSITION.

This refers to the average constitution of the rock, and the terms used are derived from chemical, mineral, or structural peculiarities, as:

Calcareous, containing carbonate of lime.

Felsitic (*Felsophyric*, J. D. Dana), having feldspar as a principal ingredient.

Arenaceous, composed of sandlike grains.

Argillaceous, consisting of clayey matter.

Ferruginous, cemented by or containing oxide or carbonate of iron. The last is sometimes called, in waters, *chalybeated*.

Siliceous, *Quartzose*, containing silica—the former in a colloid, the latter in a crystalline, form. The converse of the latter is *quartzless*, and refers only to the absence of the crystalline mineral, and not to the absence or poverty of the chemical compound, as in *basic*.

Acid, containing siliceous acid in chemical composition to such an extent that it forms the larger portion of the rock constitution. The converse is basic. (See p. 4.)

HARDNESS.

This refers to the original state of the rock, and not to the hardness after weathering. This change increases the hardness of some sandstones, limestones, and all sinters; but reduces that of felsophyres. The scale of Mohs is universally used.

FRACTURE.

This depends on texture and structure, with slight variations between fresh and weathered states, such as:

Conchoidal, when the broken surface exhibits shell-like forms, convex or concave, as in the glassy states of rocks and artificial products.

Splintery, when the surface is covered with partially separated splinters in irregular fibers.

Smooth, when, without being plane, the surface presents no irregularities.

Tabular, when the mineral forms the greater portion of the rock, and possesses a highly developed cleavage, as in some hyperites.

Crumbly, when the surface is slightly loose and sandy, as in protogine-granite.

Foliated, *Laminated*, *Slaty*, can be inferred from previous definitions.

Irregular, when the surface exhibits none of the above regular fractures.

COLOR.

The color given in each case is that of the fresh fracture of a rock, as many rocks change the color on weathering or even exposure to the air for a few seconds, in the same way as the colors on buried wall-paintings or statues that are uncovered after lying for centuries fade quickly on exposure to air and light. When certain colors are characteristic of fresh, and others of weathered, states of the same rock, the variation is one means of identification, as in phonolite. In general, it can be stated that

White shows an absence of iron or other heavy metallic oxides, either in the original composition of the rock or owing to subsequent change; but, if they occur, they have usually been reduced to the pyritiferous form by organic components of the rock, and are returned to the oxide form by weathering. Rocks containing no oxides are marble, gypsum, white kaolin, fire-clay, etc.; under rocks weathered white are some basic eruptives, especially when under peat swamps.

Black indicates carbon, magnetite, or a heavy bisilicate

(hornblende, pyroxene, etc.). In the Wyoming (northern) anthracite basin the surface is highly cultivated, and the spring and fall ploughings show the outcrops of the various beds marked by bands of blacker soil. The writer has seen strings of magnetite rotted soft in a drift-face driven to strike a hoped-for ore body.

Yellow. Dull yellow in a volcanic region may be due to sulphur, but, in general, it indicates iron ocher; bright yellow is due to pyrites. The ochers come from the oxidation of ferruginous compounds to form limonite. They are seen lining the ditches through which waters from coal mines flow, or from springs in pyritiferous rocks, and therefore indicate pyrite or marcasite at depths.

Brown indicates lignite, or hydrated iron or manganese, and the umbers are allied to the ochers in origin.

Red is due to anhydrous ferric oxide. It is a transition state in the process of complete oxidation, and is common to weathered pyritiferous lodes. In fresh rock it is seen to advantage in jasper; in weathered rock it forms the "iron hat" of the miners, and gives rise to the well-known proverb in all tongues, that may be freely translated:

> "No gangue so good as that
> Which wears an 'iron hat.'"

J. D. Dana says that the red color of many sandstones is due to a small amount of heat that the rocks have received during consolidation, as shown by the reddening of light-colored sandstones bp., and that the color of the Triassic rocks on the Atlantic border of the United States is due to the heating of the rocks and waters by trap effusions, so that high oxides of iron were distributed.

Green is found in rocks poor in silica and free quartz. If schistose, the color is due to talc, chlorite, serpentine, etc.; if massive and crystalline, to chlorites. Some intrusive

rocks were named "greenstones" from this characteristic. Decomposed copper ores sometimes make green crusts or stains; but these are on the surface only, and are not seen on fresh fractures, except in malachite.

Lustre, feel, smell, specific gravity, and other properties of rocks and minerals are used as in mineralogy.

Replacement is a term used to denote the seemingly gradual withdrawal of one mineral from the rock and the taking of its place by another. A dolerite is composed of pyroxene and labradorite. We find associated with dolerites a rock with little or no labradorite, but a great deal of nepheline, and we call it nepheline-dolerite, and say that the nepheline has *replaced* the labradorite. The replacement has taken place at the formation of the rock, by some influence that caused nepheline to crystallize, rather than labradorite. A comparison of the analyses of feldspar-basalt and nepheline-basalt shows a difference of .009 in silica, .01 in lime, and .0004 in soda, while the other ingredients vary, in the two rocks analyzed, as greatly as in two specimens of the same rock from different localities. The "replacement" of mica by hornblende or augite makes the varieties of hornblende and augite-granite. "Replacement" is used in the definitions of varieties of the same rock.

SUDDEN AND LOCAL CHANGES IN ROCKS.

In the faces of some granite quarries there are "segregations" of the same rock with the crystals of enormous size, called "giant granite," or streaks of "greisen," which are limited in extent. These are due to changes in the rapidity of cooling, or to impregnations during the fused state. In the same fissure two massive rocks run parallel to one another for a short distance; but within slight distances each may be the envelope of the other. As both are fresh, the change must have originated by differentia-

tion in a common magma during eruption. The changes from "contact metamorphism" have been already noted, and can be recognized by the study of the region. In the case of sedimentary rocks the variations are frequent and of limited extent. They may be due to a number of causes:

To a system of currents of greater intensity over parts of the area of deposit. J. F. Blandy was the first to map the river systems during the Carbonic era by the erosions of the beds during deposit and the filling of the basins with the material of the top rock. Such a case is seen when the bed thins rapidly by the coming down of the top rock for a short distance, and its sudden rising again.

To a sudden change in the conditions of deposition, as pelites are indications of deep water or feeble currents, or both; while gravels are indications of currents of considerable force. The writer has seen in the middle of a coal seam (twelve feet thick) a "parting" of fine-grained shale, averaging seven inches in thickness, that held a lenticular seam of coarse conglomerate two inches thick, and a few feet in length and width. The examination of the same parting throughout the mine, and throughout the region, failed to show a parallel instance. E. Orton reports in the coal of northeastern Ohio, two feet below the top of the bed, an angular fragment of quartz vein-stuff, as fresh as if just broken from the parent mass. The coal adhered to it on all sides, and had evidently accumulated about it, as it was undisturbed.

To a variation in conditions subsequent to rock-formation. Quarry faces, as in the Siluro-Cambrian of Pennsylvania, sometimes show that variations in porosity, or other causes, have allowed magnesia solutions to penetrate to different depths in limestone beds, so that the calcite has been irregularly turned to dolomite, and the same hand specimen will

consist of both, with the line of separation running across bedding lines.

The age of rocks can be relatively determined as follows:

A rock is always older than that which is deposited on it. In case no subsequent movement has taken place it will show that the upper rock is the younger of the two. The exceptions are:

(*a*) When a fracture has occurred along a bedding plane, and a fluid sheet has been intruded into the fracture, or when the fracture has been filled by vein material. While the sheet or vein is younger than the overlying rock, its recency can be shown by its containing fragments of the same—as "breccia" in the first case, and as "horses" in the second.

(*b*) When the whole formation has been overturned. In this case the oldest beds are brought on top, and the study of a limited area might mislead the observer, were it not that, in certain cases, the top and bottom rocks of a bed are plainly marked, as in coal, by the former containing the trunks and foliage of the vegetation, and the latter the roots. Top sandstones near a bed carry the trunks and branches of vegetation; bottom sandstones in similar conditions carry nothing, but frequently become more argillaceous. In the case of a conglomerate we can usually tell an overturn by finding the argillaceous partings that frequently occur in it or bounding it, and noting on which side the greatest amount of ferruginous staining occurs: that will be the side that was uppermost during deposition, as in gravel the percolating waters leach the iron from the mass and carry it downwards till stopped by the impervious strata, and deposit it therein or in the last few inches or feet of the porous portion—depending on the amount—of the gravel bed. After solidification that remains as a witness of the position during deposition.

A rock is always older than one that has disturbed it. The case of an intruding sheet or vein has been just described. In the case of veins or apophyses intersecting one another, the younger cuts the older. If two igneous sheets, or two veins, lie parallel to one another in the same fissure, and have been formed at different times, the younger will contain fragments of the older, as above stated. The exceptions are:

(*a*) When a cloak bedding (p. 81) has been so removed by erosion that the underlying rock is exposed, it seems to have been projected from below and to have raised the overlying strata.

(*b*) When a soluble bed has been dissolved and the overlying strata have been fractured in the resulting settling, as in the case of caverns in salt or limestone.

The relative level of two rock-formations is no criterion of their age, as the oldest rocks may be shoved upward by orogenic movements, or left by erosion. In eastern Pennsylvania the Potsdam sandstone and overlying limestone have been carried in patches upward with the Archæan mass to form the South Mountain, and thus rise hundreds of feet above the much younger Mesozoic rocks to the south and the slates to the north. The Oriskany and Medina formations make parallel ridges in the same region that remain intact, while the Marcellus (older than the former) and Lower Helderberg (older than the latter) form deep valleys on their northern flanks.

THE ROCKS.

We are acquainted with the components of the crust at limited depths by the deformation of some portions and their exposure through denudation. It has been observed that each portion of the crust maintains a temperature dependent on the local annual mean at its surface, but that there is an increase on going towards the centre. With a constant pressure at all depths there would finally be reached, even at the lowest rate of increase, a depth whose temperature would suffice to fuse all known substances, without the aid of moisture, which lowers the temperature of fusion. Volcanic extrusions prove that such temperatures exist at depths, and with an abundance of moisture, as the accompanying gases, which cause the explosive effects of eruption, contain 99% of water. Astronomically the earth acts as a rigid body, so that geologists agree that it is practically solid, and that whatever portion exists of sufficient temperature to be fluid at ordinary pressures must consist of an interstratum, between the centre and crust, so strongly compressed as to act as a solid, but which may become locally fluid by crustal adjustments which abate the pressure. The portion thus liquefied may have been formerly at or near the surface as a solid rock, or an aggregate of sediments with its interstitial water. In either case an absolute fluidity would destroy all traces of original structure and allow a rearrangement of molecules. A cooling of this

magma would produce a rock which, as far as structure or texture is concerned, might have been formed in the earliest geological period; but, as far as origin is considered, may be a complete metamorphism of an aggregate of later sediments. All rocks formed from a state of fluidity such that absolute freedom of motion existed among the molecules will be called *primary eruptive*, or *massive;* the terms *massives* and *eruptives* will also be applied.

In a fluid magma of one element there would be no tendency to disassociation, and no crystallization till the temperature approached the point of saturation. In nature the magma contains a large number of elements of varying affinities and gravities, and capable of forming bodies of widely varying fusibility. Sorby was the first to propose a theory of segregation of magmas into strata of varying densities or fusibilities, and this was modified by v. Richthofen to account for an order of effusions in a given district. Iddings has lately formulated a law that the effusions from a magna are primarily of its average composition, but are subsequently differentiated so that later outpourings become nearer the extremes of acidity and basicity with the lapse of time, and the final ones reach those extremes. In studying the extrusions of a region that are of nearly the same age, and in the examination of a specimen under the microscope, it is found that differentiation takes place before and after extrusion, so that from a magna of mean composition there may be differentiated two outflows, which show their origin by their intimate association, as an acid aplite and a basic minette from a granitic magma, a camptonite and bostonite from gabbro. The two outflows are found frequently in the same fissure, and, locally, each as the envelope of the other. It has been abundantly proven that the most basic rocks are of the lowest fusibility, and first to crystallize; that the mineral components of a given rock form in the order of

their acidity; and that the bath becomes more acid after each crystallization, so that quartz,—the most acid,—if present, fills the residual interstices. It has also been frequently shown that the crystals sink in the bath. Zirkel notes instances in granite apophyses where the intruding rock lost first its basic content of phenocrysts (mica), next the feldspar, so that the ends contained granular quartz only; and in extrusions of obsidian Becker notes that the upper portions are frequently free from crystals, and are most acid, while the crystals are accumulated at the bottom of the flow. Zirkel has compiled a multitude of rock analyses to show that the groundmass of a rock is more acid than the rock average.

Rosenbusch calls the period of original crystallization in the hot abysses *intratelluric*. With a slow rate of cooling the intratelluric crystals would continue to grow as long as the bath maintained its fluidity, and was sufficiently saturated with the necessary molecules; or until the arrival of a period when other compounds began to crystallize; or, again, until the temperature of the bath fell below the point of fluidity. As the bath became crowded with crystals the interstitial spaces would become constricted, and those minerals subsequently formed would be obliged to modify their shape unless they could push aside the enclosing members of former crops, until the mass became solid from the closing of these irregular and gradually diminishing interstices by those last to crystallize. The first to form do not always attract all of the molecular compound in the bath, as the second generations frequently show repetitions of the intratelluric forms in the groundmass. If an eruption should take place during the formation of the intratelluric crystals, they would be dashed against the walls of the fracture, through which the mass would be forced, and eroded, fractured, or fissured by the impact; or would be drawn out,

twisted, or otherwise deformed if the bath were pasty. All of these conditions are found in the phenocrysts of porphyritic rocks, and show that they were formed under the above conditions.

Primary rocks are also called *eruptive*, as they are the result of a continuous process from the original earth-throe to their solidification in circumscribed areas into which they have been forced. The variations in texture, structure, and, according to Wadsworth and Iddings, mineral composition depend on the rate of cooling. The two authorities named do not lay much stress on the influence of pressure, though others do so to a great extent, and divide rocks into "plutonic" (abyssal, abysmal, etc.) and "volcanic," or those formed at depths and at the surface. All porphyritic states can no longer be taken as evidences of intratelluric crystallization before effusion, as the researches of Judd, Van Hise, and others show that crystal-building progresses after solidification, either through devitrification or through outgrowths about crystals or grains, as some quartz-porphyries are found to be devitrified pitchstones. It will require the microscope to distinguish between original and secondary porphyritic states. Chemical bulk analyses can no longer be depended upon for separation of species, owing to the great variation in the values of the elements of the same mineralogical combination, and the high agreement between bulk analyses of widely varying mineralogical compounds. Some of the states formed under different conditions have been already described, but they can be grouped under two main heads, dependent on whether they reached the surface or not. They may be said to have a uniform abyssal origin, but we know them as eruptives. If they were forced towards the surface, but failed to reach it, they were *intrusives;* if they reached it and were effused upon it, they became *extrusives*. The former are distinguished by few or no

gas-pores (and this is considered a result of pressure), but possessing miarolitic structures (which are thought to be of similar origin); the latter are rich in vesicular states, and other evidences of a release of pressure, and a consequent escape of the included vapors. Secondary rocks will be discussed later.

PRIMARY ROCKS.

It has been conclusively proved by the finding of rhyolites extending from the present to pre-Cambrian times, and quartz-porphyries forming as late as the Eocene, that in all geological times the extrusions have been of the same character; so that no division can be made in rocks on account of geological age. Studies in Scotland, where high mountains allow the same mass to be studied at different elevations, and where the conditions of consolidation were different, have shown us deep-seated rocks running into what were once thought to be different forms that were found only at the surface. The cutting of the Comstock lode by the Sutro tunnel showed the same on a grander scale; so that the old terms "plutonic" and "volcanic" are not so far apart as some would think. In the present treatise the old terms are put aside, as all extrusives are not of volcanic origin, for the greater bulk of surface flows came from dikes. The terms plutonic and abyssal do not lay enough stress on the fact of motion in the body, as most of the rocks have been moved from their places of liquefaction, and are either thrust into or through openings in the crust, and solidify at various depths or at the surface. They are, as before stated, either *intrusive* or *extrusive*, and the later statements of Iddings allow us to be careless of the depth at which rocks solidified, as that had little to do with their mineral composition, which depending on the rate of cooling. In fine, all rocks are closely related together, and in the following

pages instances will be quoted where they have been seen shading from one species to another, or from one state to another. The mineralogical composition of rocks is taken as the basis of division, and of these minerals only those which are necessary for the rock species are meant. These *necessary* minerals can be divided into six groups, as follows:

(*a*) The black bisilicates (pyroxenes, amphiboles, micas), which are found as essential ingredients in all the modern rock systems.

(*b*) Quartz.

(*c*) Alkali feldspars.

(*d*) Plagioclases.

(*e*) Feldspathoids (nepheline, leucite, haüyne, melilite).

(*f*) Olivine.

The first of these is the basis for classification, and the various rocks will be divided as they contain one of these groups or the minerals commonly associated with them; thus, granite is a combination of mica with quartz and an alkali feldspar. Other occurrences of mica are with predominant pyroxenes or amphiboles. In the granite group mica is predominant; but the term "granite" is extended to include eruptives of predominant quartz with a small content of tourmaline, or predominant feldspar with little quartz or mica. In the same way, in the pyroxene group, gabbro consists of pyroxene, plagioclase, olivine, and magnetite. Segregations along the selvages of such dikes show rocks that are little more than aggregations of magnetite; and some authorities class this mineral as a variety of gabbro. On this basis the *mica* rocks are found to be the most *acid*, and the mica varieties of other rock groups carry the highest silica contents; the *amphibole* rocks are *intermediate* in both mineralogical and chemical constituents; and the *pyroxene* rocks are the most *basic*. Olivine is

the antithesis of quartz, and each is important where the other is rare. We arrange the rocks as:

I. Acid (mica, alkali feldspar, and quartz).

II. Intermediate (amphibole, feldspar — subordinate quartz, mica, pyroxene, feldspathoids, and olivine).

III. Basic (pyroxenes, plagioclases, feldspathoids, and olivine).

For the purpose of general description rocks can be divided into various combinations of the above minerals, no matter whether those were formed in masses, apophyses, dikes, or extruded sheets. The conditions found in dikes are simulated in the selvages of masses, while wide dikes show the same differentiations in texture that obtain in masses; and as many of the distinctions between dike and other intrusive states depend on the microscope, these states will be included under the typical combination, with a statement that they are otherwise classed by some authorities.

The acid rocks will have above 66% of silica, and the ultra-acid a great content of free quartz; their color is generally light, and their texture frequently compact-vitreous, but seldom amygdaloidal in structure. The intermediate rocks are generally darker in color than the acid, with higher specific gravity, a greater tendency to amygdaloidal states, and with fewer examples of vitreous-compact textures. The basic rocks are dark, with high specific gravity, few vitreous, but abundant vesicular and amygdaloidal states. In general, the specific gravity and percentages of soluble matter in rocks are inversely proportionate to the silica content. Acid rocks are more generally distributed over the globe, and form the axes of the great mountain ranges and systems; while basic rocks are local, and form the effusions of isolated volcanoes, or the eruptions through fissures of varying extent.

Recurring to the two main divisions of *extrusive* and *intrusive* rocks, we can distinguish intrusive rocks as more crystalline, extrusive as more compact; intrusives as lacking vesicular states, extrusives as abounding in them; intrusives as exhibiting more porphyries, extrusives more porphyritic states; intrusives as cooled under great pressure and sometimes with great slowness, extrusives as cooled more or less rapidly and under little pressure.

As an example of the association of rocks in a group, the rhyolite-granite group will be briefly described to show the method followed in this book. Granite is a coarse crystalline-granular (granitoid) rock (intrusive), which is found in large bosses which are frequently fringed by apophyses into the surrounding country-rocks. The cooling effect of the country increases as the apophyses narrow, so that the granitic filling of the fissure shows a gradual diminution in the size of the crystals till a compact texture is reached, and this changes from stony to vitreous as the fissure-end is approached. These crystalline, stony, or vitreous states may or may not contain phenocrysts, and thus form porphyritic states, or porphyries. We thus find "granite" in the crystalline state; "granite-porphyry," if microcrystalline with phenocrysts; "felsite," if stony; "quartz-porphyry," if quartz-ophyric; "pitchstone," if a vitrophyre; and "pitchstone-porphyry," if with phenocrysts. These would have an average chemical composition and be formed under pressure, but they would vary in rapidity of cooling. If a dike ran from this granitic magma to the surface, and through this a flow of fluid rock were forced during a long period, and sufficient to thoroughly heat the dike-walls, and if this flow should cease, leaving the fissure filled with molten material, and we could follow it from below to the surface, we should find the filling to be granite at such depths that the original heat supplemented by that received through the flow had been sufficient

to heat the dike-walls to, or nearly to, the temperature of the fluid filling, so that cooling could proceed slowly. Passing upward through the depths, we should arrive at points where the dike-walls were less heated, and the quicker cooling would form, with gradual losses of heat, granite- and quartz-porphyries or felsite, while the portions thrust into fissures radiating from the dike, and formed at the time of the original fracture, would form the vitrophyres. These would all be at points so far below the surface that the hydrostatic head of the fluid would act against the expanding gases sufficiently to obliterate vesicular states, or (?) the gases might escape into the porous dike-walls. As the surface was neared and the pressure lessened, the vesicular states would become more prominent; and if the dike-walls were sufficiently hot, or if the flow at the surface were sufficiently thick, crystallization would take place under conditions of great slowness; but the greatly lessened—if not almost want of — pressure would allow the crystals to form with a trachytic facies, and include between them microscopic blow-holes. A more rapid rate would cause the mass to solidify with a rhyolitic facies; while the portions forced into crevices near the surface would become trachytic pitchstones, rhyolitic pitchstones, etc., according to their facies, and the surface of the flow would show states of perlite and obsidian. Under this theory all members of the granite group may have been formed at, or nearly at, the same time and from the same magma, by variations in cooling and pressure, and all of the group are equally eruptive. According to their depth from the surface, they can be separated into:

A. The intrusive states.

C. The crystalline textures.

P. The microcystalline to compact textures, with or without phenocrysts, and non-vitreous.

V. The compact-vitreous textures, with or without phenocrysts.

E. The extrusive states.

C., P., and V. As above.

AC. Granite, porphyritic-granite.

AP. Granite-porphyry, quartz-porphyry, felsite.

AV. Pitchstone, pitchstone-porphyry.

EC. Rhyolite.

EP. Porphyritic states.

EV. Perlite, obsidian, pumice.

As the extrusive states are more common and more readily accessible, they will be first treated; but the groups will be named after both extrusive and intrusive states for readiness of correlation in the field—thus, the above group will be styled the rhyolite-granite group.

It may be well to again call attention to the fact that, in general, the vitreous states of a given rock group are more acid than the crystalline states, especially if an intratelluric crystallization began in the magma before eruption, as the more basic minerals crystallize first, and the magma thus becomes more and more acid with each succeeding addition to the phenocrysts; so that a sudden cooling would show a vitreous state more acid than the original magma. In general, the extent of the development of the vitreous states of a rock is proportional to its acidity, and in the ultra-acid rocks large masses have a glassy habit, as the obsidian cliff in the Yellowstone National Park. In basic rocks the extent of the vitreous development is contracted, till it is limited, in the ultra-base rocks, to a thin lining of vesicular cavities, thin selvages in contact with the country rock through which the eruptive was forced, thin crusts on the surface of sheets or streams, or, finally, narrow dikes of a few inches, or minute apophyses. There are very few rock groups that do not show glassy states

under both intrusive and extrusive conditions; the syenites alone have not been found with them. Many of these vitreous states are characteristic and quite readily distinguished; but in the majority of cases they cannot be determined by the naked eye, and even chemical and microscopical analyses fail to separate certain basic forms, when separated from the accompanying crystalline states. The intrusive vitrophyres can generally be distinguished from their extrusive neighbors by their lower density, and the general absence of vesicular structure. In general, the acid varieties are of lighter color than the basic; but in the same extrusive acid state, if the rock be compact, the more rapid the cooling the darker the color, as is seen in the case of furnace slags, which vary from a blackish gray highly vitreous rock to a grayish white feebly lustrous state. Many vitrophyres have lost their lustre through devitrification (see p. 61).

Extrusive rocks are found as lava streams with amygdaloidal, vesicular, scoriaceous, columnar, fluidal, and other structures. These may have issued from a central vent in recurrent streams, as in a volcano, or through an extended fissure in a single outpouring which, by cooling, closed the fissure permanently, as in a sheet eruption. Subsequent erosion removed the scoriaceous surface and reveals the filling of the volcanic vent as a *neck* or *plug*, and of the sheet as a ridge which may have a breadth measured by inches or rods, and a length up to hundreds of miles. The name *dike* is given to this denuded filling (from its shape), and thence to the whole filling, and many authorities have separated dike and volcanic extrusions on the score that vesicular states were wanting in dikes, forgetting that the lapse of time has allowed these to be removed, with the original surface, by denudation, so that we see only the filling of the fissure at depths. *Extrusions* through dikes

and plugs are therefore old ones. The rocks of this class melt at varying temperatures, of easy, medium, and difficult fusibility, which, according to Barus, are:

2250° F. for basalt and the basic rocks;

2520° F. " andesite and the intermediate rocks; and

3100° F. " trachyte and the acid rocks.

It has been found that basic extrusions are very fluid; spread over the country in thin sheets, and form mountains of low angle; while the acid types swell into lofty and circumscribed hills (*puys, mamelons*) or form cones of considerable angle. Deformations of the earth's crust accompanied by *intruded* masses produce fractures of varying sizes and dimensions. These fractures may have

(*a*) Three dimensions of considerable and comparable extent, and may run

1. Across stratification planes without unduly forcing apart the strata;

2. Along stratification planes on either side of a fissure from the side or below, and, by uplifting the overlying beds, form an arch that may be ten thousand feet in height, and of comparatively limited area along the stratification planes; or

(*b*) One small and two large dimensions. Fractures of this kind generally ramify from those of the first class, and their walls may:

3. Rapidly approach one another to form a root or wedge-shaped opening; or

4. Extend parallel to one another indefinitely, and across or parallel to bedding planes.

The material injected into these will form in

1. An irregular body that, if large, will cool slowly and, if abyssal and under pressure, as in granite, gabbro, etc., will form a *boss*.

2. A similar body that will of necessity cool under some-

what less pressure, to form a *laccolite* (Gilbert), or the modified term *laccolith* (J. D. Dana).

3. A body of limited extent, which is generally considered in connection with the body from which it is an offshoot. These bodies are variously named; but the fact of the association just given makes the term *apophysis* (plural apophyses, from Greek "an offshoot") most applicable, as "vein" is better confined to fillings of fissures crystallized from aqueous solutions.

4. A sheetlike body, which is best termed a *sheet.* If it runs across the strata and appears at the surface as a considerable outflow, the surface part is called an *extrusive sheet;* but if narrow, a *lava stream,* as in the case of a volcano. The intrusive part below the surface is variously named; if nearly vertical and across the strata, it forms a *dike;* all portions parallel to the strata form *intruded* or *bedded sheets* or *sills;* and where the filled fissure runs alternately with and across the strata, it is said to be *stepped.* Some authorities restrict the term "sheet" to surface flows, and call underground portions "dikes" or "interbedded sheets," as they happen to cut across or run with the strata.

Owing to the greater extent of bounding surface to a given bulk of injected matter in forms of the third and fourth kind, the cooling is more rapid and the size of crystals smaller. When sheets extend from deep-seated bosses to the surface, they show all varieties of structure between intrusive and extrusive rocks in the same mass. The boss shows the largest crystals towards its centre, and these diminish in size towards the walls, but not to a great extent if those walls were so deeply seated as to be within a region of great heat, or if the eruptive material had been forced through the cavity and its fissures long enough to heat the walls to a great depth. The cooler the walls the more

rapid the crystallization, until, with sudden cooling, a compact mass is formed that will show phenocrysts, in case crystallization began before eruption, and will be called a porphyry. Where pressure began to disappear, the included gases expanded to form vesicles, and the proportion of these increased with nearness to the surface where the lava was blown up to form a foamy, slaggy mass.

The primary rocks, as just stated, are grouped in three divisions, as they have mica, hornblende, or pyroxene as a *characteristic* component. This does not presuppose that they are *necessary* components of all the varieties of the division to which they belong; it indicates that the minerals grouped with it are found more frequently combined with it than with either of the other two black bisilicate groups. Each division is composed of rock series, and these are subdivided into groups *which may have in combination but one of the necessary minerals of the division*, as the gabbro series with necessary plagioclase, feldspathoids, pyroxene, olivine, and magnetite embraces groups which have but one of the above as a necessary component, as plagioclase for the anorthosites, olivine for the so-called peridotites, etc.

The following skeleton will show the method of arrangement of the rocks:

ACID DIVISION.

MICA: *Quartz*, *alkali feldspar*, plagioclase, amphibole, pyroxene, magnetite, feldspathoids, olivine.

Extrusive, Rhyolite; *Intrusive*, Granite.

INTERMEDIATE DIVISION.

AMPHIBOLE: *Feldspar*, quartz, mica, pyroxene, feldspathoids, magnetite, olivine.

Extrusives, Trachyte, Phonolite, Andesite.

Intrusives, Syenite, Elæolite-syenite, Diorite.

BASIC DIVISION.

PYROXENE: *Plagioclase, feldspathoids, olivine, magnetite*, amphibole, mica, orthoclase, quartz.

The intermediate and basic divisions will be fully arranged before the rocks they comprise; the acid division is a simple one and fully arranged above. In the following definitions the signs (*M*) and (*m*) will be used as stated in the introduction; (*M*) referring to the megascopic appearance of a rock, or the manner of its appearance as viewed with the eye or a lens, and (*m*) to the same as seen with a microscope, or of such a size that it can be seen only with that instrument.

ACID DIVISION—MICA ROCKS.

This is the most widely spread over the earth's surface, and in the greatest abundance; and it has been the longest studied of all the divisions. It comprises but one series—that of rhyolite-granite; but that is greater in bulk than all of the others combined. As the extrusives are the surface forms, they will be treated first.

GROUP I. RHYOLITE-GRANITE.

ACID EXTRUSIVES.

(Nccessary minerals: Quartz and an acid feldspar.)

I. Rhyolite.
II. Rhyolite Glass.

I. *RHYOLITE.*

RHYOLITE (v. Richthofen), Liparite (J. Roth), Quartz-trachyte (J. Roth).

A compact (sometimes cavernous or drusy) groundmass containing crystals or crystalline grains of sanidine and quartz. The latter is usually (*M*), but invariably (*m*). As (*M*) essentials tridymite and magnesia-mica and (*m*) magnetite are frequent, and both (*Mm*) plagioclase, muscovite, hornblende (in prisms), bronzite, hypersthene, and augite are infrequent or rare. As (*M*) accessories red garnet and cordierite appear in the mixture, and topaz, spessartite, and fayalite in druses.

Silica 75–82; Gr. 2.4–2.6; H. 5.5–6.

Rhyolite is not known as the lava of an active volcano, but it is abundant in beds and sheets, and in plugs and dikes. It is extensively developed in central, southern, and southeastern Europe, Great Britain, Iceland, East Indies, New Zealand, South America, and extensively in the western part of North America, and especially of the United States. A great development of devitrified pre-Cambrian rhyolite occurs along the South Mountain, across the borderline of Pennsylvania and Maryland. (See later under "Aporhyolite.")

The *groundmass* when compact is felsitic (as in quartz-porphyries), like claystone, hornstone, porcelain, and crockery-ware. The fracture is flinty, splintery, conchoidal. When cavernous, the cells or cavities are sometimes round, sometimes narrow and parallel, sometimes large and irregular. The cavities are sometimes filled with chalcedonic material, hornstone, or jasper; sometimes with quartz and amethyst, as well as the minerals noted in the definition. The structure is sometimes plane-parallel (schistose) and sometimes fluidal, with such minute divisions that each is no

thicker than a sheet of paper. The colors are white, yellowish white, greenish white, pearl-gray, reddish white, ash-gray, reddish yellow, greenish yellow, pink, and brick-red. The feel is usually smooth, but sometimes rough and harsh in the porous states. The luster is usually shining and semi-vitreous, but frequently dull and earthy. The sanidine is sometimes 5 cm. long, but in the United States has not been reported larger than 3 mm. The much-fissured and fractured crystals frequently show Carlsbad twinning. The plagioclases are of frequent appearance, but of small proportion in the mixture, and they are usually more or less completely kaolinized, so that chemical analyses are necessary to distinguish them. The quartz occurs in crystals and rounded grains, or fragments of grains, in sharp contrast to the groundmass. The color is clear smoke-gray to black, and in size up to a hazel-nut. It is distinguished (Zirkel) from that of granite by glass inclusions, that are sometimes 1 mm. thick, and by the absence of fluid inclusions. The quartz of quartz-porphyry is distinguished from the two by containing both. Many rhyolites show no (*M*) quartz, and it seldom appears alone. The magnesia-mica is biotite and frequently occurs in small quantities, and in many rhyolites it is the most conspicuous mineral, and generally abundant in American types. It is sometimes chloritized. The black bisilicates are seldom plentiful, and only in scattered cases (*M*). Hornblende is the most common, with augite and rhombic pyroxene much less prominent either (*M*) or (*m*). Tridymite is abundant in the rocks of the United States, and frequently (*M*) in druses and cavities, but not in the mixture. Of the accessories, garnet 1 mm., cordierite 1–3 mm., topaz 3–10 mm., spessartite 2.5 mm. to 1 cm., and fayalite 1 mm., occur. In some cases the groundmass is full of spherulites, which cause the rock to appear perlitic. They are sometimes 5 mm. in diameter.

(*a*) *Lithoidite* (v. Richthofen). A compact felsitic groundmass with hornstone fracture; hardness of feldspar and habit like claystone; generally light-colored; no (*M*) quartz, and almost none (*m*), so that its greater proportion of silica alone separates it from trachyte. The fresh groundmass is porcelain-like with conchoidal-splintery fracture; luster waxy, with few minerals showing.

(*b*) *Millstone-porphyry* (popular name in Hungary). A felsitic groundmass, like claystone, of dark grayish, yellowish shades, or brick-red, full of cells or cavities filled with chalcedony, hornstone, jasper, quartz, and amethyst. It contains 70% of silica.

(*c*) *Nevadite* (v. Richthofen), Granitoid Rhyolite. A difference of opinion exists as to the existence of a groundmass. Rosenbusch describes the rock as lacking one, but Zirkel calls attention to the fact that v. Richthofen noted a small proportion in his definition. There are thus types called nevadite with and without a groundmass, which, at best, is of small proportion. Nevadite is a crystalline aggregate of quartz, feldspar, biotite, and hornblende in a limited groundmass of similar composition with a microscopic or amorphous texture. Hague and Iddings report that the original nevadite of v. Richthofen is a dacite, but they found in the Great Basin a rock of the above description, and Cross found the same at Leadville.

(*d*) *Liparite.* A felsitic and porphyritic rhyolite with a stony groundmass, and bearing to rhyolite the same relation that felsite-porphyry does to felsite. Rosenbusch distinguishes sanidine and albite liparites, but the word is used more in the sense of rhyolite.

(*e*) *Soda-rhyolite.* From Berkeley Hills, Cal. Silica 75.46; Gr. 2.42.

(*f*) *Aporhyolite* (Bascom). A name given by Miss Bascom to devitrified rhyolite. It occurs in extensive masses in the

South Mountain of Pennsylvania and Maryland, and has been completely recrystallized to form a mosaic. These rocks were distinguished by the late G. H. Williams. They are pink, and retain fluxion structures and lithophysæ of large (*M*) dimensions. Subsequent action has sheared them so that slaty cleavage has developed.

The rhyolites can be told from the quartz-porphyries by the greater luster of the groundmass, and by the fewer phenocrysts; and nevadite can be distinguished from granite by the presence of a groundmass, and by the rock being porphyritic, and not crystalline.

II. *RHYOLITE AND TRACHYTE GLASS.*

The vitreous states of the rhyolites cannot very well be distinguished by the microscope from similar states of the trachytes (Group 2, with necessary alkali feldspar and one of the black bisilicates, but with a high degree of acidity) in hand specimens. Their occurrence is by far more prevalent with the more acid rhyolites than with the trachytes, but, owing to the similarity of the states of these rocks, they will be described together, as chemical analyses are necessary to distinguish between them. We unite, therefore,

Group 1. Rhyolite-granite (necessary minerals quartz and an alkali feldspar);

Group 2. Trachyte-syenite (necessary minerals an alkali feldspar and hornblende).

PERLITE, Pearlstone.

A matrix, sometimes glassy, more frequently enamel-like, pearly, or greasy on a fresh fracture, containing many round grains of a concentric or shaly structure.

Silica 70–82; water 0–4; Gr. 2.3–2.4; of the spheroids, 2.37–2.54.

The color is mostly pale gray, lavender-blue, and dark

gray, though sometimes yellowish brown. The spherules vary in size from 1 mm. to an inch in diameter. They are probably caused by contraction in the cooling mass, as in some basalts. They are sometimes shelly; sometimes compact, and sometimes radially striped. Their composition is felsitic. The rock frequently contains nests and cracks which are lined or filled with fire-opal, precious opal, jasper, and semi-opal.

(*a*) *Porphyritic Perlite*, showing, with the spherules, abundant phenocrysts of sanidine and plagioclase (with sometimes anorthoclase), black mica in sharply defined lustrous folia, and sometimes pyroxene and hornblende. Quartz now and then occurs, and in one or two instances hypersthene and bronzite. Occasionally red garnets are found.

(*b*) *Obsidian-perlite.* This is a state when the dense mass preponderates and the spherules are not abundant.

(*c*) *Vesicular Perlite.* Here the mass is more or less vesicular, and the color grows lighter with the percentage of pores till it becomes snow-white. In this mass the spherules are sporadic.

(*d*) *Trachytic Perlite.* A perlitic glass colored from light to dark or greenish gray, with sanidine, plagioclase, and biotite—at times hornblende and augite. This occurs with trachyte at Cervetri, near Sasso, Italy, and elsewhere. The majority of the perlites are states of rhyolite.

These rocks are found with the rhyolites abundantly in the Lipari Islands, in Hungary, New Zealand, Mexico, and the western part of the United States. They occur in thick lava-streams and in dikes. A variety is

Marekanite (Herter). A velvet-black mass from Marekanka, Siberia, with abundant small glass spherules of smoke-gray to orange-brown color, and great transparency.

RHYOLITIC PITCHSTONE.

A vitreous or semivitreous compact rhyolitic glass of high acidity and varying color, with greasy or pitchy luster, and invariably containing chemically combined water.

Silica 66–80; water 3–10; Gr. 2.2–2.4; H. 5–6.5.

Both rhyolite and trachyte are accompanied by pitchstones, but, as the greater number occur with rhyolite, the assembled specimens are placed under the name of the former. They bear to them the same relation that the felsite pitchstones do to the quartz- and felsite-porphyries. They are found at Hlinik, Hungary, in Italy, the Hebrides, Iceland, Nevada, Utah, Mexico, and South America. They are mainly of a dirty green, dark-brown, or black color, and conchoidal fracture. Though they may have the same luster as obsidian, they can be distinguished from it by their content of water, as obsidian does not carry above one per cent. They commonly show (*m*) phenocrysts of white or colorless feldspar (sanidine or plagioclase), and sometimes augite and quartz. Rarely and in inconsiderable amounts they show (*m*) garnet, biotite, what seems to be anorthoclase, pyrite, pyrrhotite, and gold. They melt with more or less difficulty to a frothy glass or a grayish-greenish enamel, and give water in the closed tube. They are untouched by acids.

(*a*) *Trachytic Pitchstone-porphyry.* At Eigg, Hebrides. A velvet- to violet-black, very slightly lustrous rock, rich in sanidine and single plagioclases of large size, prisms and grains of augite, and particles of magnetite; also pyrite (Italy) and olivine (Gough's Island). Silica 61–71.

(*b*) *Perlitic Pitchstone.* From Massai Land, South Africa. A glass carrying perlitic spherules with (*M*) quartz, bluish grains of arfvedsonite, and (*m*) sporadic brown hornblende and feldspar.

(*c*) *Pumiceous Pitchstone.* All pitchstones of this group show (*m*) an abundance of minute vesicles from the expanding steam. These are usually drawn out from the flow of the mass, and occasionally they are so expanded and so abundant as to form a pumice.

RHYOLITIC OBSIDIAN, Volcanic Glass.

A compact glass of varying color and luster, of high acidity, and with content of chemically combined water never more than one per cent.

Silica 70–77; Gr. 2.35–2.45 (average 2.4); H. 6–7.

Obsidian is a volcanic glass and forms the surface of quickly cooled acid lava-streams. In general, the thickness of the glassy state is inconsiderable; rarely—as at Obsidian Cliff, Yellowstone Park—it forms a rock of extensive dimensions which is entirely of this state. It is found less frequently with trachytic than rhyolitic effusions. In the western part of the United States it is extensively developed, also in Mexico, and the natives used it for knives, heads for spears and arrows, axes, etc., some of which have been found east of the Mississippi. In its compact state the steam vesicles are not abundant (*m*) in the average specimens; but whenever found they are egg-shaped or drawn out to threadlike openings, with the longer axes parallel to the line of flow. Fluxion-structures are common. The color in the transparent varieties is generally uniform, but streaks and parallel banded varieties are common. The shades are light or dark gray, green, grayish blue, and yellowish brown. It is sometimes almost colorless, and sometimes so black as to be translucent only on thin edges. It fuses on the edges of thin splinters, but gives no water in the closed tube. Its hardness is greater than that of basalt glass.

(*a*) *Typical Obsidian.* A clear, transparent glass, free from crystals or inclusions of any kind. It is found on the edges

of streams as thin crusts, in Siberia, Iceland, and New Zealand, and also occurs in large masses as above stated.

(*b*) *Porphyritic Obsidian.* An obsidian mass carrying (*M*) phenocrysts of sanidine, plagioclase, laminæ of biotite, augite, and quartz, or some of them. This is common in certain parts of the mass.

(*c*) *Spherophyric Obsidian*, when the glassy mass carries colorless, grayish white, yellowish, bluish waxy spherulites of more or less radial structure, which sometimes have a parallel arrangement.

(*d*) *Lithophysic Obsidian*, when the spherulites are concentric and form lithophysæ (p. 78). They are generally rich in (*m*) minerals, sometimes visible with the lens, as olivine, fayalite, quartz, tridymite, etc.

(*e*) *Vesicular Obsidian*, when the mass contains a large proportion of vesicles, so as to make a slaggy structure, with stretched and parallel arrangement. This is transitional to pumice.

(*f*) *Trachytic Obsidian.* This is found on the surfaces of trachytic lavas in Italy, the Azores, and elsewhere. It is a yellowish, greenish, brownish, or pitch-black transparent glass with feldspar, biotite, and much augite. Contains silica 60–63; Gr. 2.44. It occurs in porphyritic, pitchstone-like, and vesicular states.

(*g*) *Bottlestone* (Ger. "Bouleillenstein") Pseudochrysolite, Moldauite. From near Moldauthein, Bohemia, and elsewhere. This is held by varying authorities to be natural and highly siliceous glass, and, on the other hand, to be an artificial product. Rutley says that it is the former. It occurs in large grains and spheres of transparent glass one inch thick, with irregularly distributed steam vesicles, in sand near the above place, also in tuffs. Contains silica 82.70. Similar glasses have been described from other localities, with silica 76–81, and Gr. 2.17–2.35. The break-

ing of the surface vesicles produces a pitted, corrugated, and wrinkled surface.

(*h*) *Obsidian Bombs.* Clear glass without phenocrysts in shape of bombs, from Australia, and with Gr. 2.41–2.52.

PUMICE.

A highly porous and frothy state of rhyolitic obsidian, of light colors, whitish, grayish, yellowish, greenish, but seldom blackish.

Silica 73; Gr. 2.37.

This is the surface state of a rhyolitic-trachytic effusion, and occurs especially developed in the Azores, Lipari Islands, Iceland, Mexico, and South America, and in some of the western States of the Union. To a smaller extent it is found on all surface flows of undenuded condition. The pores are sometimes caused by a trachytic structure of the magma, but more commonly by the steam vesicles. It fuses more readily than obsidian before the blowpipe.

(*a*) *Obsidian-pumice.* This is the pumice of commerce, free from phenocrysts, of extremely light colors, approaching white, and is extensively found in the Lipari Islands and Iceland.

(*b*) *Perlitic Pumice.* In this rock the tendency to spherulitic structure was stopped by extrusion to the surface. The vesicles are extremely stretched and parallel, so as to form only threadlike openings, and among them are minute perlitic spheres, as well as phenocrysts of sanidine, biotite, and quartz. This is quite common in Hungary.

(*c*) *Porphyritic Pumice.* In the Eureka district in Nevada, and elsewhere, the foamy mass carries (*M*) and (*m*) phenocrysts of sanidine, plagioclase, biotite, augite, quartz, magnetite, and sometimes red garnet. In some cases the pores are filled with opal.

(*d*) *Trachytic Pumice.* A vitreous foamy mass, coarse,

fibrous, and felty, a cross between a typical pumice and a crystalline magma. This is a transition between obsidian pumice and the porphyritic state.

(*e*) *Trachyte-pumice.* A dark-colored foamy state of trachyte-obsidian, greenish brown, brown, or black, with 62 per cent of silica. It occurs in Italy, the Azores, New Zealand, Philippine Islands, Hungary, and in small exposures in many other localities.

GROUP II. GRANITE (CÆSALPINUS).

ACID INTRUSIVES.

(Necessary minerals: Quartz and an alkali feldspar.)

This group is compounded of the above necessary minerals, associated with the more acid of the plagioclases; sparingly of the amphiboles, and still more sparingly of the pyroxenes. With these are combined a large number of accessories. The group is characterized by a variety of states, dependent on varying conditions of solidification, and, as granite is one of the most extensive and well-known rocks, each of these states has been distinguished by a special name. There is no region of the globe without granite, and in each it is similarly situated with regard to other formations, as a foundation, where seen, upon which they have been deposited. It forms the axes of extensive mountain systems, as bosses and laccoliths intruded into later rocks, and as dikes and apophyses which penetrate other rocks—even older granites. They afford evidences of their heated state during intrusion by the extensive metamorphism of their enveloping country-rocks, which will be more fully treated under "Metamorphic Rocks." Some authorities class metamorphic granites with gneisses, and others place the gneisses formed from squeezed granites with them as original states. In this work all rocks that have lost traces

of secondary origin will be treated as primary. The English authorities are more disposed to treat all granites as eruptive, while a large number of American authorities place them as the result of complete metamorphism; but they have been thrust into cracks and cavities, so that they exhibit all the apophyses, etc., of eruptive granite, and cannot be told from it in hand specimens. As solidifying under pressure, there are neither vesicular nor amygdaloidal states, though some authorities think that miarolitic structures represent the former. It occurs usually massive, and with thick tabular-jointed structure, and weathers spheroidally to form a kaolin, more or less colored by the iron from the black bisilicates, which contains as angular grains the quartz content of the original rock; or, in certain loosely cemented and porous varieties, the grains separate to form sand that may be metamorphosed to form *arkose*, or granitic sandstone.

It has already been stated that crystallization in the original magma originated either with the most basic of the mineralogical components or, when one composition was greatly in excess, with the predominant compound. In acid granites the quartz is one of the first crystallizations, as shown in quartz-porphyry (unless this state is formed from a subsequent devitrification and crystallization of pitchstone, as Judd and others have shown that crystallization can take place in solid rocks). In the average granites the feldspar is greatly in excess and forms the idiomorphic component, while in the basic granites the black bisilicates are first crystallized. The average granite, therefore, shows generally well-crystallized feldspar, with mica following next, and quartz last. With slow cooling the crystals touch one another on all sides, and the quartz keys the others into a firm mass, with "granitic habit," unlike the porous and open "trachytic" texture of some of the rhyolites, where the crystals touch one another only at one or two points. The

members of the granite-group are named according to the relative time when and the suddenness with which intratelluric crystallization was checked. We distinguish:

I. The entirely crystalline state without (or with few) phenocrysts, and with no base of any sort. Under this is:

(*a*) Entirely crystalline and without phenocrysts, as typical granite.

(*b*) The same with phenocrysts, as porphyritic granite.

II. The subcrystalline state, which is caused by cooling rapid enough to produce a varying proportion of stony (felsitic), but not glassy, base, as:

(*a*) A crystalline groundmass with more or less base, and carrying phenocrysts, as granite-porphyry.

(*b*) A stone (felsophyre) groundmass carrying phenocrysts of quartz and perhaps of other minerals. This can be defined as a "quartzophyric felsophyre" (Dana), or quartz-porphyry. When the phenocrysts of quartz become sporadic, or entirely disappear, it becomes

(*c*) A felsophyre with phenocrysts of orthoclase (orthophyre) or plagioclase (plagiophyre), and with little or no visible quartz or felsite-porphyry.

(*d*) A felsophyre without phenocrysts, as felsite.

III. The vitrophyric state reached by a cooling rapid enough to form glass, as:

(*a*) A vitrophyre with phenocrysts of some of the component minerals and spherules of felsite, as pitchstone-porphyry.

(*b*) A clear vitrophyre without phenocrysts, as pitchstone.

Ia. GRANITE.

A coarse- to fine-grained completely crystalline compound of quartz and an alkali feldspar (usually orthoclase, often microcline) and a mica. As essentials, acid plagioclase (usually oligoclase, often albite, now and then andesine), and sometimes hornblende; rarely a pyroxene.

Silica 60–82; Gr. 2.59–2.73.

This is an important economic rock in the United States, but has been most highly developed in New England, whence over one-half of the output for 1891 was taken. It is found wherever the Archæan is exposed. The uniformity of its grain increases with its fineness. In the so-called "giant granite" the ingredients are in large masses. The medium-coarse texture is so peculiar to this rock that it supplies the adjective "granitoid" to similar textures in other mineral combinations. A very fine texture forms a "microgranite," as in the states found in dikes and apophyses, which are both of fine grain, and, as in quickly cooled states, of higher acidity than the average. The quartz in granite is in angular grains with greasy-vitreous luster, conchoidal fracture, and grayish-white to light-gray color. It is sometimes light blue, dark blue, bluish gray, dark red, and smoky. It fills the interstices between the other minerals, as it was the last to crystallize completely, and locks them together. It frequently occurs crystal in double pyramids, and then, contrary to its habit, is idiomorphic with respect to feldspar, the opposite usually being the case. As crystal it is sometimes $\frac{1}{8}$ of an inch in size in ordinary granite; in giant granite it occurs in large masses. In *graphic* granite and *pegmatite* it forms thin plates along certain cleavage-planes of the feldspar (microcline). It is not affected by weathering. The orthoclase is mostly in regular crystalline

grains. On fresh cleavages it shows a pearly luster. The color is usually reddish white, flesh-red, or yellowish white, infrequently grayish or greenish (amazonstone), rarely deep red, reddish gray, grayish blue. When very fresh, it has a luster like adularia, rarely like sanidine. Twinning occurs generally in porphyritic phenocrysts, not in granitic grains. It twins mostly according to the Carlsbad law (some are five inches long) also that of Baveno. It weathers to mica, kaolin, talc, pyrophyllite, and epidote. Microcline occurs alone; intergrown with orthoclase; and replacing it as in pegmatite. Microperthite is frequently found (*m*). Mica is either in thin irregular folia or hexagonal tables, and scattered sporadically through the mass, except along the selvages of bosses and dikes, where it sometimes (from pressure, or the influence of the cooling surface) has its planes arranged parallel to the walls of the country-rock to form a schistoid structure. It also occurs in spherical and lenticular concretions. While muscovite and biotite are generally separate from one another, they are sometimes found (Rosenbusch) in the same folia, one being the rim to the other, or in the same tabular crystal, where they form alternate folia, so that optical tests are necessary to distinguish between them. In general, biotite predominates over muscovite in amount and in regularity of crystallization. Biotite is the more basic, and in varieties of average composition is the earliest crystallization of those already named, and this accounts for its greater regularity of form. It is usually dark brown to iron-black, and seldom greenish. Lepidomelane also occurs in black folia, often of large size. Zinnwaldite is found in tin-bearing granites (greisen) in black folia, brown to brownish red by transmitted light. Muscovite is more irregular in its habit than biotite and crystallizes after it, but usually before the feldspars. It occurs in folia and rhombic tables. Lepidolite rarely occurs in ordinary gran-

ite. Rosenbusch describes it as the mica in pegmatite. Of the essentials, oligoclase occurs in tabular crystals which are generally idiomorphic with respect to orthoclase and quartz. It is less transparent than the former. To a small extent it forms pegmatitic structures with quartz. Albite and andesine occur now and then in the more basic granites, and labradorite has been reported in one case. Plagioclase is found more abundant in the granitites (biotite-, hornblende-, and augite-granites). Hornblende usually crystallizes in long regular prisms with irregular terminations. It sometimes has a uralitic habit. Augite is not common, and then (*m*) in long thin prisms or crystalline grains. Light yellowish brown bronzite occurs in rare cases. Calcite sometimes occurs in what seems to be a primary crystallization; but more generally it is a secondary product in the so-called "kalkgranit." In rare cases altered olivine occurs (*m*).

To ascertain which minerals are idiomorphic to others it is only necessary to remember that crystallization proceeds from basic to acid. In granite the principal necessary, essential, and accessory minerals can be arranged as follows: zircon, apatite, magnetite, specular hematite, ilmenite, biotite, pyroxene (usually an alkali variety), hornblende, lepidolite, muscovite, the lime-soda plagioclases, albite, orthoclase, microcline, quartz.

In the Brocken granite shades into gabbro in a narrow zone through augite-biotite-granite, augite-diorite, diorite, and quartz-biotite-augite-gabbro. In Skye some fragments of porphyritic hornblende-granitite, included in a later gabbro, have been heated so that the granophyre between the phenocrysts has been changed to rhyolite glass full of flow-lines, spherulites, lithophysæ, etc. In Sweden Nordenskiöld reports that hälleflinta is a devitrified rhyolite that shades into aplite, and that into granite.

The (*M*) accessories in the United States include the following species and the following localities: *Maine:* Paris—tourmaline; Readfield—andalusite. *Massachusetts:* Chester—spodumene; Chesterfield—cassiterite; Greenfield—columbite; Gloucester—danalite; New Bedford—molybdenite; Goshen—cassiterite, tourmaline; *Connecticut:* Haddam—anthophyllite, allanite, chrysoberyl, columbite, gahnite, garnet, zircon; Middletown—columbite; Trumbull—topaz. *New York:* Greenfield—apatite; Warwick—rutile. In addition to the above there are found in foreign localities cordierite, fluorite, graphite, native gold, pyrite, specular iron, allanite, chlorite, and hydromica. Granites also carry concretions of varying size and composed of various mixtures of the components. The granite group embraces the following varieties:

(*a*) **GRANITE** (Muscovite-biotite-granite, "Eigentlicher Granit" of Rosenbusch—not of G. Rose; "Zweiglimmeriger Granit" of Zirkel).

A granite composed of quartz, orthoclase, more or less plagioclase, and both muscovite and biotite in about equal amounts.

With predominating muscovite or biotite it passes into those varieties. Hornblende is rare and pyroxene absent, garnet abounds, and cordierite occurs. It is coarse- to fine-grained and porphyritic. This variety is the great mountain-former, but also occurs in bosses and dikes. It is found in Germany, the Vosges, France, extensively in Cornwall and other parts of Great Britain, Spain, Mexico, and in New England. Rosenbusch places here the occurrences with tourmaline, while Zirkel puts them under biotite-granite (granitite). The former states that tourmaline has been formed at the expense of biotite. As muscovite-granites are rich in tourmaline, garnet, topaz, cassiterite, etc., and as the

tourmaline rocks, etc., are drusy, they will be placed under muscovite-granite.

(*b*) **MUSCOVITE**-granite (Rosenbusch).

A granite composed of quartz, orthoclase, some plagioclase, and muscovite.

Silica 75.

This is the most acid of the varieties; the richest in quartz, and the poorest in basic silicates, magnetite, etc. It occurs less frequently in dikes than the other varieties. Biotite may occur to a small extent. It runs to extremes in texture, either fine-grained or very coarse. It is frequently drusy, but porphyritic states are rare. It is rich in accessory minerals, especially tourmaline, garnet, topaz, cassiterite, etc., and is found extensively in Europe, throughout New England, and in the western States. Here may be placed:

1. **Pegmatite** (Haüy) Graphic Granite. A compound of reddish feldspar, quartz of dark color, and silver-white mica, so arranged that the rock consists almost entirely of the former, which is pierced along certain cleavage-planes by the quartz so as to produce figures similar to Assyrian or Hebrew letters. The mica is in aggregates, or arranged parallel to the quartz tables, and frequently coating them. A coarse texture forms *pegmatite*, a fine one *graphic granite*. Both form dikes and subordinate masses in granite, and dikes and interbedded intrusives in metamorphic schists. They are of limited extent, are associated with an abundance of accessory minerals given above, and contain 78 per cent of silica. According to the best authorities, the feldspar is microcline and the mica lepidolite. V. Cotta calls the granites rich in feldspar, which have their content of mica arranged in stripes or branching as flower-stalks, *blumengranit* (Ger.). It occurs in Germany, France, Sweden, and Normandy.

2. **Aplite,** Granitell, (Ger. "Halbgranit"). A dike-granite of uniformly fine grain, composed of quartz, orthoclase, and some plagioclase, generally without mica, or with a very small amount of silver-white or greenish potash-mica. It occurs mostly in dikes, but in one or two cases it is widespread. The localities of the typical rock are few. It is found in Hungary, the Vosges, Germany east of the Rhine, in South Africa (with calcite). It is distinguished from granulite by its want of schistose structure and the absence of metamorphic minerals, especially garnet. According to the later differentiation theories, this is the "complementary" rock to minette from a granitic magma. In the Melibocus a dike runs from the gneiss on the east side to the granite on the west side. The filling in the gneiss is micaless aplite; in the granite, *alsbachite*, a highly micaceous granite-porphyry.

3. **Cordierite**-granite. A rock of limited occurrence in Norway, Greenland, Bavaria, Australia, in which cordierite (iolite) is abundant and mica scarce. Gr. 2.6–2.7.

Here follow a series of rocks formed during granitic eruptions through the influence of what the French authorities call "mineralizing agencies." These are the gases accompanying the ascent of the magma, and which some authorities think were absorbed during the cooling of the earth from a nebulous to a fluid state, and which are included in all magmas. Acid magmas are supposed to possess them to a high degree; some authorities would substitute the word "retain" for "possess," as acid magmas are less fluid at the time of eruption and gases can less readily escape from them than from those more basic and fluid. The "mineralizers" are aqueous vapor, fluorine, boric acid, and other volatile acids—the ones acting on the following rocks being those named. These in their effort to escape leave the

greater part of the magma, but are entangled in other portions (according to one view); or they are forced into the still molten mass along lines of greater fluidity (according to another view), and form new compounds, some of which are pseudomorphs after the original minerals, such as tourmaline, topaz, cassiterite, lepidolite, zinnwaldite, fluorite, etc. These rocks are:

4. **Tourmaline**-granite. A granitoid compound of orthoclase, quartz, and tourmaline, with little or no muscovite. Gr. 2.6–2.9. Here tourmaline replaces biotite (Rosenbusch). It occurs in Saxony, at Predazzo, Italy (in typical form), near Eisenach, Hungary, at the Eibenstock (where the tourmaline is frequently in masses as large as the head), in Bohemia, near Heidelberg, in the Tyrol, Spain, etc. Tourmaline-bearing muscovite-granites are found in the Vosges extensively, and elsewhere. In some instances they are pegmatitic, and with tourmaline one foot long. The other tourmaline compounds will be placed here to group them in a compact body, though they may fall under other varieties of granite.

(*a*) *Luxullianite* (Pisani). This is named from the parish of Luxullyon, Cornwall, where the rock occurs in loose blocks (not massive). It is a dark mass composed (*m*) of a quartz ground filled with hairlike tourmalines, and carrying large grains of the same, small orthoclases, and beautiful large phenocrysts of the same, of yellowish-red color, two inches in size, and flecked with spots of tourmaline. The tourmaline is said to be an altered zinnwaldite.

(*b*) *Trowlesworthite* (Bonney). Another Cornish granitic compound of reddish orthoclase, acicular tourmaline, purple-red fluorite, and scanty quartz. The fluorite has replaced the quartz so as to form one-fifth of the whole mass.

(*c*) *Hyalotourmalithe* (Daubrée), *Carvoeira* (von Eschwege),

Tourmaline-quartzite, Tourmaline Rock. These are names of two extremes in composition of a Cornish granitic segregation which has been formed, through the entrance into the body of the mass, and not along its selvages, of fluoric or boric ingredients as exhalations. The tourmaline has grown at the expense of the feldspar and mica. In some cases there is a small amount of orthoclase in the mass or in the many drusy cavities. The mixture of black tourmaline (blue or brown by transmitted light) and quartz as a granular compound is the "tourmaline-quartzite," while the aggregate of tourmaline with little or no quartz is the "tourmaline rock." "Carvoeira" is the name given to a similar rock in Brazil.

5. **TOPAZ ROCK**, Topazfels (Werner), Topazosème (Brongniart).

A usually granitoid rock which is sometimes (owing to the age of its formation) greatly decomposed by weathering. It is composed of predominant topaz (which sometimes forms 90 per cent of the mass), with quartz, mica (frequently zinnwaldite), cassiterite, tourmaline, sphalerite, and fluorite.

The first noted occurrence of the rock was at the Schneckenstein in the Voigtland, where a dike of tourmaline rock has broken through phyllite and formed a breccia. Both phyllites and breccia are impregnated with topaz. In this case it is a secondary rock, but it occurs at the Eibenstock, Markersbach, and elsewhere as a regular crystalline primary rock, and is, therefore, placed here rather than among the secondary rocks.

6. **GREISEN** (Old German mining name), Hyalomicte (Brongniart).

A grayish granitoid compound of light-gray quartz and a grayish, yellowish, or greenish mica (zinnwaldite).

Silica 80.

This is another granite without feldspar, as the exhalations have replaced this and other minerals, so that quartz is found pseudomorphed after feldspar (which is sometimes twinned) and mica, while cassiterite forms pseudomorphs after feldspar, similarly twinned in some cases. It is of limited extent and is valuable as the gangue of cassiterite. It resembles granite in its irregular jointing, and is associated with it in strings and pockets. Scattered through it are cassiterite, fluorite, tourmaline, and topaz. It is found in Saxony, Cornwall, and the Black Hills, S. Dak. When cassiterite is uniformly scattered through the rock, it forms *tin*-granite.

7. **ZWITTER ROCK.**

A medium- to fine-granitoid, dark-green (or gray) compound of (*M*) quartz, with smaller topaz and cassiterite, with or without (*m*) potash-iron mica.

Quartz 50–70%.

This is the gangue of the tin ore of Altenberg, Saxony, called "zwitter." The quartz is all that can be detected by the naked eye, the other ingredients being visible only through the lens. With this are associated mispickel, micaceous hematite, and chlorite.

8. **Epidote**-granite, Unakite. A granite with epidote abundant. It is an altered granite, the epidote coming from the black bisilicates, mica, or hornblende (sometimes feldspar). It is found in the Fichtelgebirge, Schwarzwald,

Pyrenees. In the United States a variety with flesh-red feldspar, quartz, and epidote, from the Unaka Mountains, N. Y., and from Tennessee, is called *unakite*.

(*c*) **GRANITITE** (G. Rose), Biotite-granite.

A basic granite composed of quartz, red orthoclase, plagioclase, and magnesia-mica (biotite).

Silica 67–70.

This is the most widely disseminated variety of granite. It occurs in bosses and dikes, is denser than the muscovite variety, and does not, like it, contain drusy cavities. It abounds in porphyritic states and in plagioclase, and (as shown in the silica content) is poorer in quartz than any of the other varieties. As a basic variety it is richer in hornblende as essential, and, by its increase, shades into hornblende-granite. In this case there is a diminution in orthoclase, and a still further loss of quartz, so that the excessive reduction of these two components causes it to shade into quartz-diorite and diorite. As the muscovite-granites are rich in essential tourmaline and quartz, these basic granites are free from the former, and almost free from garnet and iolite (cordierite); but magnetite and specular hematite are higher than in other granites. It is found in Germany, Bohemia, Tyrol, Alsace, Italy, Corsica, Great Britain, widely spread in Sweden, in Greenland, China, Australia, the western continent, and especially western North America. A small amount of hornblende and augite causes varieties that take those minerals as adjectives, as *hornblende*-granitite, *augite*-granitite.

1. **Kalkgranit** (Pichler), Lime-granite. From the Flaggerthal in the Tyrol. A granitoid compound of quartz, biotite, dark-green chlorite, reddish orthoclase, white plagioclase, and transparent particles of calcite. Granites with

calcite occur in the Odenwald and in Sweden, and Hawes found it at Columbia, N. H. While some authorities find that calcite is an infiltration product, others see in it a primary generation.

2. **Hornblende**-granitite (Rosenbusch). A granite with an equal amount of hornblende and biotite. These granites occur in the Scottish Highlands, Saxony, Alsace, the Odenwald, Fichtelgebirge, the Channel Islands, Scandinavia, the Troad, and, in the United States, in the Wasatch, Shoshone, and Havillah mountains, at the famous quarry at Quincy, Mass., and in Minnesota.

(*a*) *Kammgranite* (Groth). A porphyritic variety much developed in dikes in the Vosges, with silica 62.

(*b*) *Rapakivi* (Finnish local name). A "rotten stone"—hence the name—extensively distributed near Wiborg, Finland. A coarse-grained aggregate of egg-shaped orthoclase (never crystalline) up to two inches in length, of brownish-red color, and covered with a scaly shell of oligoclase, lepidomelane, and hornblende, and generally of two or more colors. The darker has irregular dark-gray quartz scattered through it; the lighter and weathered state has the quartz more crystalline and the feldspar more weathered. Silica 70. The high silica content is due to the leaching of the alkalies.

(*c*) *Granio-diorite* (Becker). A granite poor in potash, with predominant plagioclase, orthoclase, quartz, hornblende, and brown mica. With orthoclase in excess it is a hornblende-granitite; with little orthoclase, it is a quartz-mica-diorite. Silica 60. It is the rock of the Yosemite Valley.

3. **Augite-granitite** (Rosenbusch), Pyroxene-biotite-granite. A granitite with usually monoclinic pyroxene (augite). The localities are noted below under the varieties.

(*a*) *Gabbro-granite* (Törnebohm). From Haakanbols,

Sweden, where it is composed of gray plagioclase, orthoclase, brown mica, green diallage (or a diallage-like augite), hornblende, and quartz. As accessories are titanite, magnetite, and apatite.

(*b*) *Augite*-granite. A gabbro-like granite, with monoclinic augite, rich in plagioclase and biotite. The pyroxene in all these varieties is the idiomorphic mineral. It occurs in England, Labrador, the Vosges, etc., and the augite is frequently uralitized.

(*c*) *Augite-soda*-granite. A red, drusy, fine-grained granite, sprinkled with dark spots. It is composed of orthoclase, anorthoclase, quartz, and augite, with accessory hornblende, biotite, apatite, sphene, and secondary chlorite. Silica 66–72. This is said to be one of those very infrequent occurrences —an alteration product of a sediment as it occurs between eruptive gabbro and slate. It is reported from St. John, N. B., and Minnesota.

(*d*) **HORNBLENDE-GRANITE** (Naumann), Syenitic Granite (v. Cotta), Syenite (in part, of G. Rose).

A granite usually poor in quartz, with little or no muscovite, but generally containing biotite, orthoclase (and sometimes red microcline), plagioclase, and hornblende.

Silica 71.78.

It occurs in bosses, dikes, and widely distributed masses in Saxony, Bohemia, Austria, Sweden, Finland, Pyrenees, France, Great Britain, Greece, Mount Sinai, Egypt, Altai Mountains, and in the United States in Minnesota, Nevada, and Canada. The quartz is variable from abundant to rare. In the former case biotite fails. Plagioclase is more abundant than in biotite-granite (granitite). Orthoclase varies in color from light to deep red; plagioclase is usually

white. Hornblende is in green crystals (sometimes over an inch long) and sometimes appears uralitized. Titanite and apatite, malakolite (or a diallage-like augite) and rhombic pyroxene, are accessories. It is frequently porphyritic from large phenocrysts of orthoclase. Unfortunately for the name "syenite," both the localities whence its name might be derived (Mount Sinai, and Syene, Egypt) have this variety of granite.

(*e*) **PROTOGINE-GRANITE,** Jurine (Haüy), "Alpen-granit" (Studer).

A granite breaking with a sandy, crumbly fracture, composed of abundant quartz, scanty dark biotite, abundant sericite, white orthoclase, microcline (and sometimes an orthoclase), with accessory small (*M*) grains of garnet, pyrite, titanite, hornblende, and sometimes large beryls.

Silica 66–76.

This is extensively developed in the Alps and is the mass of Mont Blanc. The sericite was formerly thought to be talc or chlorite. The rock has undergone extensive alteration, so that in addition to the change of biotite to sericite the plagioclase has become saussurite, and the orthoclase kaolin and sericite. On the peripheries of the granite masses there is a widely developed change of structure from massive to schistoid, as will be noted later.

Here follow a series of variations in texture and structure that effect all or most of the foregoing granites to a greater or less degree, and also some variations in the ingredients that are insufficient to cause the rock to form a definite subspecies:

Miarolite (Fournet). This is a cavernous, drusy granite, rich in soda or soda-potash feldspars "Mialolo" is the

Italian folk-name for the rock. The specimen described by Fournet came from Lyons. It is also found in the Vosges; the Mourne Mountains, Ireland; and in Italy. From this structure Rosenbusch has drawn the name *miarolitic* for all drusy granites. The structure is peculiar to the muscovite varieties.

Spherophyric Granite, Pudding-granite, Variolitic Granite (v. Chrustschoff). A granite containing concretions of a concentric-shaly (rarely of a radial) structure. This is not common in granite; but is more frequent with varieties rich and hornblende than in muscovite. The con- composed of predominant mica; of scanty mica (at Craftsbury, Vt.); of concentric layers of alternately rich and poor in mica; of a horn- feldspathic kernel with external growths, as aggregates of pegmatitic structure, and (in Finland) as apparently uniform bodies. These minute grains to masses eighteen inches in di- he rock is found in the Fichtelgebirge, France, weden, and in the United States in Colorado, Vt., southern Rhode Island (where the concre- he rare radial structure), and in California.

Granite. Here will be placed those states found ges of dikes and bosses where, through pressure fter cooling, the minerals, especially mica, as- sition parallel to the walls of the country-rock. ese states have been classed with the gneisses, as -gneiss, but, even when they are of large extent, e traced to a central portion which shows no iation. They are also found in shear-zones, so ay have schistoid structures imposed on rocks eir undergoing sedimentation. When these result in a perfect foliation, the rock must be classed as secondary, but the transitional states that are

THE following may be taken as representative of the chemical composition of granite and syenite: Granite—Silica 72.07, alumina 14.81, peroxide of iron 2.22, potash 5.11, soda 2.79, lime 1.63, magnesia .33. Syenite—Silica 59.83, alumina 16.85, peroxide of iron, 7.01, lime 4.43, magnesia 2.61, potash 6.57, soda 2.44.

neither massive nor schistose will be styled "schistoid," as above. Under this will come the alternations of granite and tourmaline rock in Cornwall, the parallel arrangement of minerals in dike-selvages, etc. Examples of this are found at Port Deposit, Md.; and abundantly along the shores of Lake Superior, in Europe, etc.

PORPHYRIES OF THE GRANITE GROUP.

IIa. GRANITE-PORPHYRY (Kittel).

A brownish, greenish, sometimes yellowish, but generally not very dark, completely crystalline (*m*) groundmass of predominant feldspar and quartz, carrying phenocrysts of orthoclase (gray, flesh-red, brick-red), mostly twinned, yellowish or greenish plagioclase, gray to dark-colored grains of quartz, plates and hexagonal tables of brown mica, or rounded aggregates of chlorite; with accessory magnetite, zircon, apatite, pyrite, infrequent titanite, rarely red garnet, iolite, or pinite—the accessories generally (*m*).

Silica 61–75; Gr. 2.6–2.7.

It occurs almost entirely in large dikes which have parallel structures along the selvages, as in other dike-forms, especially when mica is present. In the Eureka district, Nev., the selvages of a granite dike are granite-porphyry. It is unknown in surface forms, and is found abundantly in the Thuringian Forest, the Drusenthal, Erzgebirge, Bohemia, Vosges, France, Egypt, China, and in the western United States at Goose Creek, Franklin Buttes, Eureka district, Nev., and Parkview Peak, Col. It is intermediate between granite and quartz-porphyry, which it becomes by gaining a felsitic base. The groundmass is (*m*) wholly crystalline with predominant feldspar, which is idiomorphic with respect to quartz, and interlocked by it as

in granite. Black bisilicates are rare in typical forms with a full quartz content; but biotite and chlorite appear as quartz disappears. Muscovite is of little importance except in the porphyries of kammgranite (see p. 130). The quartz is sometimes as large as a walnut. Feldspar varies between tabular and prismatic shapes; orthoclase is sometimes three inches long; plagioclase is usually oligoclase or oligoclase-andesine, but is seldom more basic. Biotite is in sharply defined hexagonal tables, and alters to chlorite. Hornblende is green (seldom brown), and chloritizes and epidotizes readily. Pyroxene is usually monoclinic and green, and usually serpentinized or chloritized—it also alters to carbonates. The three black bisilicates are in nearly equal proportion, but the local increase of each enables us to distinguish varieties. The most common is with biotite, as the micas have the greatest affinity for acid minerals.

(*a*) **Granitic** Granite-porphyry (v. Cotta), where the matrix can be recognized as extremely fine-crystalline, but where it carries phenocrysts of all the three granitic minerals, quartz, orthoclase, and mica. Common in the Erzgebirge, near Freiberg, in the Thuringian Forest, etc.

(*b*) **Biotite-granite-porphyry.** Under this variety comes the original granite-porphyry noted by Kittel from Aschaffenburg.

1. *Aschaffite* (Gümbel). A fine-grained to compact mass, rich in mica, and with hornblende and augite, carrying phenocrysts of quartz and sporadic large feldspars (single and twinned); but all have their edges rounded by abrasion received during eruption, so that sections are elliptical. The large mica content makes this rock a transition to the kersantites, so that it may be complementary to an aplite form of granite by differentiation from a granitic magma.

2. *Alsbachite* (Chelius). From the west side of the Melibocus. Silica 73–75. It occurs in a dike in granite; brown

or red; with (*M*) quartz, feldspar, large laminæ of mica, and rose-red garnets. The filling of the same dike changes to aplite when it enters the gneiss of the east side of the mountain. Here we have the differentiation of granite in the same dike.

(*c*) **Hornblende**-granite-porphyry, where hornblende is quite abundant among the other phenocrysts. It occurs in the Vosges (where it resembles minette) and in Nevada.

(*d*) **Pyroxene**-granite-porphyry, with abundant phenocrysts of pyroxene. It occurs in Minnesota, Sweden, etc.

Grorudite (Brögger). From Grorud, near Christiania. A fine-grained, greenish (*m*) groundmass of orthoclase, ægirite, and quartz. A similar rock from Varingkollen afforded silica 74.5.

(*e*) **Chloritic** Granite-porphyry (v. Cotta), Green Porphyry (Naumann), so-called "Syenit-porphyr," where the black bisilicates have chloritized, and the rock assumes a greenish color. The groundmass is fine- to micro-crystalline, and brown to dark green, and composed of flakes of chlorite, quartz, and feldspar, with phenocrysts of the same. It is found in the Erzgebirge, and elsewhere in Germany.

II*b*. **QUARTZ-PORPHYRY**, Elvan (Cornish mining term), Quartzophyric Felsophyre (Dana).

A compact groundmass not resolvable (*M*), carrying phenocrysts of quartz, orthoclase, and generally plagioclase, with one or more of the black bisilicates.

Silica 69–81; Gr. 2.5–2.7.

It occurs principally in dikes, which have intersected, and been extruded upon strata of varying ages from early geological time down to the Eocene. In one case the dike was 30 feet wide and 16 miles long. These dikes, as usual, send apophyses into the dike-walls, and contain more vitreous

states of the rock. It rarely occurs in intruded sheets or isolated plugs. It is found in Germany, Belgium, Tyrol, Transylvania, Bohemia, Great Britain, France, Sweden, Italy, Spain, Sardinia, Corsica, Egypt, Japan, China, Brazil, and in the United States in New England, Pennsylvania, Michigan, Colorado, Nevada, etc. It is the porphyry of granitite (biotite-granite). The groundmass fuses in thin splinters bp., and is Vogelsang's "granophyre" (see p. 56), and may be micrographic or micropegmatitic; its reddish color is due to ferrite (see p. 53). Of the phenocrysts, quartz varies from minute grains to the size of peas, either rounded or in double pyramids, with grayish or dark smoke-gray color and vitreo-greasy luster. When (*M*) quartz disappears, the rock becomes Tschermak's *felsite-porphyry*. (*m*) both granitic and trachytic structures are seen in the quartz, as would be the case when it formed under great or small pressures. Orthoclase is usually colorless, yellowish-white, or flesh red (and of lighter color than the groundmass), and its cleavage surfaces have a strong pearly luster. It occurs in tabular or prismatic shapes, as in granite-porphyry; and the large phenocrysts commonly twin in Carlsbad forms, less frequently in those of Baveno, least in those of Manebach. Stout twins an inch long are frequent, and with (*M*) inclusions of other minerals. A sanidine-like habit in the feldspar causes a trachytic facies in the rock. The Washoe quartz-porphyry carries feldspar of so vitreous a habit that it was misnamed dacite (when fresh) and quartz-propylite (when weathered). Plagioclase is distinguished from fresh orthoclase by its white color, its softness and incipient kaolinization, so that striations are infrequent. It is usually oligoclase or one of the albite-oligoclase series. Perthitic structures are common between orthoclase and plagioclase. These minerals (*m*) are usually like their forms in granite; but

orthoclase in many cases has the habit of sanidine, as just mentioned. Orthoclase weathers to kaolin, muscovite, and sericite; plagioclase epidotizes. Microcline is not as abundant as in granite. Biotite shows hexagonal dark-green or brown tables; muscovite is seldom alone in the groundmass, but sometimes is one-third of an inch in size. Only few varieties carry hornblende in abundance; it is sometimes in prisms visible with a lens, as in the Truckee rock. Pyroxene is as in granite. As accessory (*M*) minerals are cordierite (iolite), garnet (Twin Mountains., N. H.), tourmaline, topaz, fluorite, orthite (Colorado), and zeolites. Some varieties have abundant concretions, as in granite. The structure of quartz-porphyry varies from massive to amygdaloidal, cavernous, fissured, and cracked. The first two are filled with calcite, quartz, chalcedony, hornstone, opal, jasper, and amethyst; the others only with crystals. Occasionally a vesicular structure with parallel arrangement is met with (cavities sometimes two inches long). In rare cases small slaggy particles appear in the dense groundmass, which may be pyroclasts of portions of the first eruption that cooled against the dike-walls, and have been partly re-fused in the mass. In addition to concretions there are also compact, radial, or concentric-shelly spheroids, which are sometimes like rhyolitic lithophysæ (South Mountain, Pa. and Md.). (*M*) fluidal structures are common, especially along selvages. Quartz-porphyry weathers to *clay-porphyry*, *claystone*, and kaolin. It occurs with irregular fissures; sometimes with columnar and tabular jointing, as in basic dike-rocks. The great proportion of accessory minerals is due to infiltration into the cracks, nests, etc. Dendritic markings are common, as well as stainings from ferruginous solutions, as the mass weathers. Spheroïdal weathering is rare.

a. **Typical Quartz-porphyry.** A compact matrix with phenocrysts of quartz, feldspar, and sometimes mica and

hornblende, rarely pyroxene. According to the texture of the matrix it can be divided into:

1. *Hornstone-porphyry*, Elvan, with a cryptocrystalline groundmass that breaks with a splintery fracture like chert, and has a faint glimmer or waxy luster on a freshly broken surface. It will strike fire with steel, but can be told from hornstone by its fusibility.

2. *Felstone-porphyry*, when the compact mass is not so hard, and has a smoother fracture.

3. *Claystone-porphyry*, Argillophyre, when there is a rough, almost earthy groundmass, soft enough to be cut with a knife. This is the state of (1) and (2) after weathering. This last occurs extensively at Leadville, Col., under the name of *white-porphyry*. It joints readily into blocks, whose faces are covered with dendritic markings.

4. *Pyritiferous Porphyry*. A decomposed hornblende-biotite variety, with those minerals replaced by pseudomorphs of pyrite. From Leadville, Col., where it has been formed from quartz-porphyry by the action of thermal waters charged with H_2S. The hornblende-biotite variety is found in a fresh state at depths in the mines, but near the outcrops the hornblende has disappeared, and is represented by pyrite, as above stated, while the biotite has been altered to chlorite and pyrite. The quartz-porphyry of Freiberg has a small quartz content and carries pyrite.

(*a*) *Beresite* (G. Rose). A dike-rock from Beresowsk in the Urals, and elsewhere which is much decomposed. It shows kaolinized orthoclase and plagioclase, pyrite, and not much quartz nor mica, and occurs with auriferous veins. It was once thought to be a dike-form of muscovite-granite, but Helmhacker places it under quartz-porphyry.

5. *Slaty Porphyry*, Band Porphyry, Striped Porphyry. The result of flow, and composed of layers of different color, composition, or texture. These are usually parallel to

the selvages of the dike; are often bent and twisted, and (*m*) are found to be of alternately coarse- and fine-crystalline texture. In many cases the parallel arrangement of color is accompanied by a decided schistose structure, so that the rock splits more readily with than against the layers. Another variety of slaty porphyry is due to orogenic forces. Examples of the first are found near Freiberg, in the Thuringian Forest, etc.; of the second, in Switzerland, France, Nassau, etc.

6. Millstone-porphyry, Drusy Porphyry, Porous Porphyry. A quartz-porphyry filled with irregular druses and geodes, which are usually the result of weathering, are not vesicular, and are lined with thin layers of hornstone, chalcedony, amethyst, calcite, fluorite, specular iron, etc. It is quarried for millstones (whence the name), and is found in the Erzgebirge, Thuringian Forest, Fichtelgebirge, Odenwald, Schwarzwald, etc.

7. Vesicular Porphyry. A rare variety, with numbers of steam blow-holes (sometimes two inches long), drawn out by flow and arranged in parallel structure, or with small vesicular pyroclasts enclosed in a dense groundmass. The former is found at Rochlitz, Saxony, and Friedrichroda, the latter in the Falkenstein. In some cases these are filled with quartz and specular iron to form *amygdaloidal porphyry.*

8. Pyromeride (Haüy), Ball Porphyry. A variety abounding in spheroids in addition to the usuai crystals. It is found in the Thuringian Forest, Harz, Corsica, Eiba, Sardinia, Jersey, and in the western United States and in Pennsylvania. The balls are compact, radial-fibrous, and shelly. Some are like lithophysæ in rhyolite, and the rock may have been derived from that extrusive by devitrification. The cavities in the balls are filled with hornstone, agate, etc. It is found with both microgranitic and micropegmatitic groundmasses.

(*b*) *Sanidine*-quartz-porphyry. A variety containing sanidine from Baden-Baden, southern Tyrol, and Zwickau, Saxony. These are geologically late varieties, and, probably on that account, near the tops of the dikes. The feldspar is fresh sanidine, with high luster, well fissured, and easily fractured.

(*c*) *Hornblende*-quartz-porphyry. A variety with large ($\frac{1}{12}$ inch) hornblende columnar phenocrysts, in a greenish-gray to grayish groundmass. It is found at Mount Sinai, the Pyrenees, Sardinia, France, Germany, Corea, Scotland, and Nevada.

(*d*) *Pyroxene*-quartz-porphyry. A variety with pyroxene phenocrysts that can be distinguished with a lens (sometimes $\frac{1}{25}$ inch long). It is usually monoclinic and serpentinized. The rock is found in Siberia, Alsace, England, Egypt, and in New Hampshire at Waterville.

IIc. FELSITE-PORPHYRY (Tschermak).

A quartz-porphyry where the quartz is in (*m*) phenocrysts, and the only (*M*) phenocrysts of feldspar appear.

As quartz is in phenocrysts, though (*m*), the rock is a true quartz-porphyry. The groundmass is colored red or brown by ferrite, and shows phenocrysts of feldspars, hornblende, and specular iron. It is found in Sweden, Nassau, China, etc.

Here belong the states of Gümbel's *keratophyre*, which are quartzose and have a compact groundmass (see "Keratophyre," p. 155). Such a *soda-orthoclase*-quartz-porphyry is found at Pigeon Point, Minn., as a (*m*) fine-grained groundmass, of dark-red or purple color, carrying phenocrysts of greenish-white and brick-red feldspars. It is said to form the contact product of gabbro on slate. If so, it is an instance of a transition between a sediment and an eruptive.

GRANITIC FELSOPHYRES.

II*d*. **FELSITE** (Gerhard), Eurite (Daubuisson), Petrosilex (Brongniart).

A compact rock as hard as feldspar; yellowish, reddish, gray, greenish, bluish; weathering white, with dull, smooth, conchoidal, or fissile fracture. It has the same (*m*) composition as the groundmass of quartz-porphyry, and like it fuses in thin splinters.

Silica 71–81; Gr. 2.5–2.7.

It occurs in masses 1500 feet thick, and in dikes, abundantly in Great Britain and in Saxony, elsewhere less abundantly as a state of quartz-porphyry. It has a massive-jointed structure, but is not so much fissured as quartz-porphyry. Devitrification has been claimed as the agent which has altered this from an extruded glass. In many cases it holds spherules, which Rutley claims to indicate that the rock in question is a devitrified perlite. It shows fluxion and parallel structures, and in this respect resembles hälleflinta, which v. Cotta classed here, and which has just been shown to be a devitrified rhyolite. Parallel structures are shown on a grand scale in Great Britain, where high mountains are formed of this rock.

GRANITE GLASS.

III*a*. **PITCHSTONE-PORPHYRY,** Vitrophyre (Vogelsang).

A compact glass, with considerable water, of greasy, resinous luster, conchoidal fracture, translucent on thin edges, with the hardness of feldspar; colored olive-green, blackish green, yellowish brown, brownish red, and black; exhibiting (*M*) phenocrysts of vitreous feldspar, laminæ of mica (biotite), grains of quartz, and reddish spheroids.

III*b*. **PITCHSTONE,** Retinite.

A similar glass entirely free from phenocrysts and spherules.

Silica 63–76; Gr. 2.25–2.4; water 5–8%.

This occurs in beds or sheets 2000 feet thick, also in bosses and dikes, and usually associated with quartz-porphyry. It is especially found in the vicinity of Meissen, the Fichtelgebirge, Tyrol, Italy, Arran, Scotland; and in the United States at Isle Royal, Lake Superior, and in Colorado. The groundmass (*m*) is seldom free from phenocrysts, which are of the minerals noted under quartz-porphyry. There are two types of the rock—trachytic and felsitic—associated with the rocks of the name. They are alike at sight and under chemical analysis, and only the microscope can distinguish between them. Orthoclase is fresh and like sanidine; plagioclase is oligoclase-labradorite: quartz occurs in double pyramids. In the groundmass are (*m*) augite, hornblende, apatite, zircon, magnetite, tridymite, and hyalite, but rarely and scantily. The regular spheroids vary from (*m*) proportions to six inches, and the irregular ones may be two feet. The smaller ones are felsitic (sometimes like sanidine), with starry internal cracks lined with (*m*) quartz, chalcedony, agate, etc. The larger ones are irregular, sometimes angular and with re-entering angles, sometimes roughly rounded as by abrasion. These latter are pyroclasts of quartz-porphyry, and even spherulitic pitchstone rent from older masses, and somewhat metamorphosed, as their peripheries are more dense than their interiors. They contain spherules of different character from those of the enclosing mass (near Meissen), and are older than it, as their nodules are rusty and weathered. The Planitz (Saxony) pitchstones contain mineral charcoal pyroclasts from coal deposits through which they have broken. Those near Zwickau and Wechselburg show devitrification, as the selvages are quartz-porphyry (with a crystalline groundmass in the latter instance).

Argillaceous Pitchstone, Pitchstone-felsite (Naumann), "Argilorétinite." From near Meissen, somewhat weathered, wax-yellow or olive-green, conchoidal fracture, and greasy luster. Silica 79.85.

INTERMEDIATE DIVISION—AMPHIBOLE ROCKS.

These are intermediate in two ways—through the alkali minerals (orthoclases and feldspathoids), and through the lime-soda minerals (plagioclases), as follows:

I. ALKALI SECTION:

(*a*) Groups 3 and 4. *Alkali feldspar*, plagioclase, feldspathoids, quartz, mica, pyroxene, magnetite, olivine.

Extrusive, Trachyte; *Intrusive*, Syenite.

(*b*) Groups 5 and 6. *Alkali feldspar, feldspathoids*, plagioclase, quartz, mica, pyroxene, magnetite, olivine.

Extrusive, Phonolite; *Intrusive*, Elæolite-syenite.

II. ALKALI-LIME-SODA SECTION:

(*a*) Group 7. *Alkali feldspar, mica*, quartz, plagioclase, pyroxene, magnetite, feldspathoids, olivine.

Extrusive, none; *Intrusives*, Syenitic Mica-traps.

(*b*) Groups 8 and 9. *Plagioclase, mica*, quartz, pyroxene, alkali feldspar, magnetite, olivine, feldspathoids.

Extrusive, none; *Intrusives:* Group 8, Dioritic Mica-traps; Group 9, Porphyrite and Mica-porphyrite.

III. LIME-SODA SECTION:

(*a*) Groups 10 and 11. *Plagioclase*, mica, quartz, pyroxene, magnetite, alkali feldspar, olivine, feldspathoids.

Extrusive, Dacite; *Intrusive*, Quartz-diorite.

(*b*) Groups 12 and 13. *Plagioclase*, pyroxene, mica, alkali feldspar, magnetite, olivine, feldspathoids, quartz.

Extrusive, Andesite; *Intrusive*, Diorite.

(*c*) Groups 14 and 15. *Plagioclase, pyroxene*, magnetite, olivine, mica, feldspathoids, alkali feldspar, quartz.

Extrusive, Pyroxene-andesite; *Intrusive*, Pyroxene-diorite.

GROUP 3. TRACHYTE.

Ia. TRACHYTE-SYENITE EXTRUSIVES.

(Necessary minerals: Amphibole and an alkali feldspar.)

TRACHYTE (Haüy).

A rough, porous, (*M*) microcrystalline or aphanitic groundmass carrying (*m*) a small proportion of glass base with a felt of minute crystals of sanidine (and generally plagioclase), with small amounts of the black bisilicates, magnetite, and titanite, and showing large (*M*) phenocrysts of sanidine, plagioclase, and (in small proportions) hornblende, augite, and magnesia mica. Quartz, nepheline, and leucite are absent, and olivine generally so.

Silica 58–67; Gr. 2.6; H. 5–6.

Trachyte occurs in dome-shaped masses, generally in lava-streams, infrequently in dikes, also in tuffs. It is extensively developed in western Germany, Hungary, France, Spain, Italy, Asia Minor, East Indies, Azores, South Africa, New Zealand. It forms the greatly extended and most *acid* of recent lavas. The groundmass differs from that of rhyolite in the almost entire absence of a vitreous portion, and fewer developments of fluxion structure. Zirkel states that the roughness of the groundmass is due to (*a*) the fact that the crystals of the mass are not intergrown, as in granite, but touch at but few points, so as to leave interstices, and (*b*) that there are many round or egg-shaped gas-pores which form trachyte-pumice when they comprise the greater part of the mass. Trachyte is generally considered a porphyritic rock. The usual colors are brownish, yellowish white, reddish, gray, and (rarely) bluish. The name refers

to the rough feeling of the groundmass (from the Greek for *rough*) when the fingers are rubbed over the fractured surface of a fresh specimen. The pores above mentioned cause the rock to fracture irregularly and unevenly. The luster differs from that of rhyolite in being dull, and, at best, clayey and semivitreous. The feldspar seems to be the prevailing mineral. Of the phenocrysts, sanidine appears in tabular crystals, crystalline grains, and fragments. Twinning occurs in Carlsbad and Baveno types. Anorthoclase is reported in an acmite-trachyte from South Africa, and microcline in an andesitic variety from the Azores. Plagioclase occurs, striated and white, with high luster, but in much smaller individuals than does sanidine. The old divisions into sanidine and oligoclase trachytes were based on the (*M*) examination of the phenocrysts, but they cannot hold, as plagioclase is generally present in all trachytes, and especially in the groundmass, and the divisions are now made by many authorities on other grounds. The plagioclase is usually oligoclase; but albite, andesite, and labradorite occur in a few specimens. Of the black bisilicates (hornblende, augite, and biotite), the greater proportion occurs as phenocrysts, and not in the groundmass. They form large individuals sparsely scattered through the mass. Augite seems to be the only one that appears alone, or in company with either of the others. Hornblende occurs in large, lustrous, black, stout prisms, long needles, or irregular grains. The prisms have the habit of basaltic hornblende. In the groundmass arfvedsonite and ægirite appear (*m*). Hornblende is altered to chlorite and epidote in some trachytes. Monoclinic augite is seldom (*M*) (as in the Drachenfels variety). Acmite is occasionally found. Rhombic pyroxene (hypersthene) is rarely (*M*). Magnesia-mica in black folia is common in many trachytes (*M*). It is generally biotite and in hexagonal leaves. It is usually absent

from the groundmass, which can thus be distinguished from that of minette, when the trachyte carries a large proportion of the mineral. Magnetite (*m*) is more abundant than in rhyolite, and can be gathered from the powdered rock with the magnet. Epidote and titanite occur as (*M*) accessories. Olivine is generally absent; quartz, nepheline, and leucite always so; haüyne is present in rare cases; apatite and zircon usually present, as in all rocks, in small amounts, but (*m*).

I. **Typical Trachyte** (of Rosenbusch). A compound of feldspar with phenocrysts of either or both of the minerals hornblende and biotite, while augite is confined to the groundmass. Under this are distinguished:

1. Biotite-trachyte.
2. Biotite-hornblende-trachyte.
3. Hornblende-trachyte.

Under the second comes the so-called "oligoclase-trachyte," or *domite*, from the Siebengebirge and the Puy de Dôme (whence the name). It is a dark-colored compound of oligoclase, hornblende, and biotite, with (*m*) augite. Silica 62–68; Gr. 2.6–2.8. It is reddish, soft, and sandy.

Typical trachytes occur in Germany, Hungary, France, Bohemia, Italy.

II. **Augite-trachyte** (of Rosenbusch). A compound of feldspar with phenocrysts of monoclinic pyroxene, while mica and hornblende are absent, or play a very unimportant part. This variety is important in Italy.

1. *Acmite*-trachyte (Mügge). First noted from the Transvaal, also from Crazy Mountains, Mont. In the latter regions it is in sheets, dikes, and laccoliths. The rock is composed of a groundmass of lath-shaped feldspars and acicular ægirites and acmites, with colorless interstitial matter, and carrying phenocrysts of anorthoclase, sodalite, and augite. The interstitial matter is composed (?) of nepheline and analcite. Silica 62.17.

III. **Phonolitic Trachyte** (of Zirkel). A compound of feldspar (sanidine, anorthoclase, oligoclase), augite, sparse biotite and hornblende, (*m*) ægirite and acmite, and (in druses) sodalite and sometimes nepheline. Nepheline does not occur as a typical ingredient of the mixture. These trachytes are found at Monte di Cuma, Ischia, San Miguel and Terceira of the Azores, and Massai Land, South Africa. Its greenish groundmass is sometimes schistose.

IV. **Andesitic Trachyte** (of Mügge). A dark to blackish gray compound of feldspar (mostly triclinic), with a great proportion of (*m*) black bisilicates and ores in the groundmass, which carries a distinct amount of dark-colored glass. Among the phenocrysts appear feldspars of good size, augite, biotite, and sometimes olivine. Hornblende is rarely present. The microstructure is trachytic, and thus separates the rock from the andesites. The rock epidotizes and uralitizes. It occurs at Schemnitz, the Arso lava of Ischia, the Azores, and Mont Dore in Auvergne.

V. **Hypersthene-trachyte** (J. F. Williams). This is a rock first studied at Monte Amiata, with 63–67 per cent of silica. It is andesitic, but of grayish or reddish color, with sanidine, hypersthene, and a high acidity. *Bronzite*-trachyte is reported from Japan.

To the trachytes are annexed certain rocks that are found geologically connected with them, as:

VI. **Laacher Trachyte** (v. Dechen). In the tuffs about the lake of Laach are round masses of a sanidine-trachyte not found in place in the neighborhood. It is partly compact, partly porous, light- to dark-gray groundmass, with phenocrysts of white sanidine, and partly intergrown with them and partly in druses are haüyne (or nosean), hornblende, augite, mica, olivine, plagioclase, and titanite. The groundmass often carries an abundant porous glass. In the Azores

is a somewhat similar rock. This is also called *haüyne*-trachyte.

VII. **Sanidinite** (Zirkel), Sanidine Bombs. These occur at the same place, and are composed of a soda-sanidine, haüyne (or nosean), augite, hornblende, biotite, plagioclase, scapolite, garnet, nepheline, olivine, hypersthene, calcite, apatite, and magnetite. There is neither quartz nor leucite. It occurs also in the Azores.

The trachytes occur generally compact, porous, and porphyritic; sometimes the pores become so numerous as to form scoriaceous states on the surface of lava-flows, but the vesicles are never filled, and the rock is never amygdaloidal. With the entrance of nepheline the rock passes into the phonolites; with the addition of a glassy groundmass and the absence of alkali feldspars, to the andesites; and with the entrance of free quartz, to the rhyolites. The products of contact metamorphism are similar to basalt.

(For "Trachyte Glass" see p. 111, where it is described with rhyolite glass, owing to the similarity between them.)

GROUP 4. SYENITE.

Ib. TRACHYTE-SYENITE INTRUSIVES.

(Necessary minerals: An alkali feldspar and amphibole.)

SYENITE (G. Rose).

A granitoid compound of an alkali feldspar and hornblende (with mica, pyroxene, and without quartz).

Silica 55–63; Gr. 2.7–2.9.

All of the varieties of this group contain hornblende, but some have the other black bisilicates predominant, or as prominent as hornblende, so that varieties are formed by the variation of minerals. There is also the same variation in texture due to rates of cooling as in granite, so that the following divisions are generally recognized:

I. Hornblende-syenite, or typical syenite.
II. Mica-syenite.
III. Pyroxene-syenite.
IV. Syenite-porphyry.
V. Syenite-aphanite.

These are quartzless granites. This statement must not be taken as preventing the admission of a small amount of that mineral to form quartzose varieties, but a large amount would form quartz-poor granites. V. Cotta states that near Dresden a transition from syenite to granite can be traced in the same mass. As augite is a usual component of nepheline mixtures, the augite-syenites are more nearly connected with the elæolite-syenites than the other members of the group. The more basic the rock the more plagioclase is found accompanying, and replacing, orthoclase. Syenites occur in the same forms as does granite, but in smaller bosses and fewer dikes. They joint less readily than granite, and do not weather spheroidally as readily. They differ from the diorites in their feldspar. A fine-grained syenite is sometimes confused (*M*) with diorite, but it can be distinguished by its being red or gray, while diorite is dark or green. Diorite is usually more fine-grained than syenite; oligoclase weathers faster than the hornblende, so that the latter is prominent on a weathered surface, but the rock remains solid; orthoclase and hornblende weather more nearly together in syenite, so that the rock falls into a rusty sand. Diorite carries more pyrite, syenite more titanite. When other signs fail, the fusibility of the feldspars usually settles the question.

"Syenite" is a misnomer, as the original syenites did not come from Syene, Egypt, and Rozière's *Sinaite* would be no nearer correct, as the rocks in both localities are hornblende-granite.

I. **HORNBLENDE**-syenite.

A granitoid compound of an alkali feldspar and primary hornblende, with plagioclase, occasionally biotite and quartz, and usually magnetite, titanite, and apatite.

It is found in Saxony, the Thuringian Forest, Great Britain, Norway, Sweden, Bulgaria, Russia, Greenland, New Zealand, Nevada, Arkansas, Massachusetts, etc. Orthoclase is usually flesh-red, yellowish red with bluish schiller, sometimes white; common in Carlsbad twins, rare in Baveno. Microcline is now and then present. Both alter as in granite. The plagioclase belongs to the soda end of the series. Hornblende occurs in stout prisms, dark-green, grayish black to black (greenish by transmitted light). Biotite occurs in brown (sometimes green) irregular folia, and replaces the hornblende, not the feldspar. It is the oldest generation of the necessary minerals. Quartz occurs sparingly, and occasionally forms a micropegmatitic texture. It is usually (*m*). Apatite occurs more abundantly as the mixture grows basic. Concretions of the black bisilicates with scanty plagioclase are common. The texture is medium to coarse granitoid, and frequently porphyritic from large feldspar phenocrysts in some dike-forms, which are usually of orthoclase (sometimes three inches long), while plagioclase is absent as phenocrysts. In some localities there is a parallel arrangement of alternate feldspathic and hornblendic mixtures. As accessories occur titanite, zircon, garnet, orthite—never tourmaline; as secondary products hornblende epidotizes, while feldspar remains fresh to form *epidote*-syenite.

(*a*) *Nordmarkite* (Brögger). A quartzose syenite of flesh-red color, medium grain, minute drusy structure, composed of feldspar (orthoclase, microperthite, and acid oligoclase) and quartz, with biotite, hornblende (arfvedsonite or glaucophane), light-green pyroxene, sparse ægirite, titanite, zircon, apatite, and iron ores. Silica 60–64.

II. **MICA**-syenite, Biotite-syenite.

A rare variety with predominant mica. It is found in Austria, Norway, Italy, Greenland, Black Forest, etc.

Silica 51.

(*a*) *Durbachite* (Sauer). A biotite-syenite with large phenocrysts of orthoclase over $\frac{1}{2}$ inch long.

(*b*) *Augite-bearing Mica*-syenite. In Norway, as a transition between the mica- and augite-syenites, carrying anorthoclase, cryptoperthite, oligoclase, hornblende, lepidomelane in tables nearly half an inch square, and augite. Silica 55.18.

III. **PYROXENE**-syenite.

A syenite with predominant pyroxene. The feldspar is orthoclase (also anorthoclase and microperthite) and a soda-rich plagioclase. The pyroxene may be a titaniferous diallage or diopside, augite, hypersthene, or uralite. Mica is usually biotite, sometimes lepidomelane; elæolite is seldom absent in some varieties. Hornblende is brown. Olivine is usually present, and quartz and plagioclase absent. In color it is grayish, greenish, brick-red, blackish green, and violet-red when weathered. It resembles gabbro in some varieties.

Silica 55–59.

This combination is not a common one, though it is of importance in Norway, Italy, and less prominent elsewhere.

(*a*) *Orthoclase-monzonite*. A compound of orthoclase, plagioclase, hornblende, and augite, with an abundance of the ores. At Monzoni, Italy, and in Silesia.

(*b*) *Laurvikite* (Brögger). From southern Norway, with 56.8–58.8 silica. A grayish gabbro-like rock composed of brown hornblende, the soda-orthoclases, titaniferous pyroxene, biotite, and some nepheline and olivine.

(*c*) *Akerite* (Brögger). A quartzose variety of the above and at the same place, carrying orthoclase, plagioclase, quartz, hornblende, pyroxene, brown biotite; no nepheline, sodalite, nor olivine. It is in a laccolith; medium- to coarse-grained and granitic; gray to red. The variety from New Hampshire described by Hawes is like this.

(*d*) *Hypersthene*-syenite. Zirkel places here the "*norite*" of G. H. Williams, from Cortlandt, N. Y., as it contains orthoclase.

(*e*) *Uralite*-syenite (v. Jeremejew). A uralitized augite-syenite from the Urals.

PORPHYRIES OF THE SYENITE GROUP.

IV. **SYENITE-PORPHYRY** (v. Richthofen).

This subgroup includes the quartzless orthophyric felsophyres that exhibit phenocrysts of one or more of the black bisilicates to form a series which has the same relation to syenite that quartz-porphyry has to granite. According to the mineral of the phenocrysts which shows predominantly, they are divided:

(*a*) Felsophyre with orthoclase phenocrysts is *quartzless orthoclase*-porphyry, or *quartzless orthophyre*.

(*b*) Felsophyre with phenocrysts of orthoclase, hornblende, biotite, and augite, *syenite-porphyry*.

(*c*) The same with orthoclase and hornblende is *hornblende*-syenite-porphyry.

(*d*) The same with orthoclase and biotite is *biotite*-syenite-porphyry.

(*e*) The same with orthoclase and augite is *augite*-syenite-porphyry.

IV*a*. QUARTZLESS ORTHOCLASE-PORPHYRY, Quartzless Orthophyre (according to J. D. Dana).

A feldspathic groundmass in which only potash-feldspar occurs in phenocrysts, with no appearance of black bisilicates except as (*m*) in the groundmass, where they are usually altered to secondary products, such as calcite, chlorite, and hydrated ferric oxide.

Contains silica 56–62; Gr. 2.55–2.60.

It occurs in dikes and sheets in the Thuringian Forest, Tyrol, the Balkans, Scotland, Greenland. These rocks are separated from the quartzless felsite-porphyries by their lower acidity. The groundmass is light to dark through shades of red, yellow, gray, and green, and consists almost entirely of (*m*) feldspar crystals — usually orthoclase — with the alteration products of the black bisilicates. It seems to be entirely without base, and holocrystalline. The glassy habit of the feldspar gives it frequently a trachytic appearance. Orthoclase is milk-white, yellowish, or reddish; plagioclase is almost absent.

1. **Rhomb Porphyry** (L v. Buch). From Norway. The light-violet groundmass carries deep-gray crystals of orthoclase, which give rhombic sections. When weathered the mass is reddish. It is compact and shows (*m*) orthoclase, augite, magnesia-mica, olivine, and magnetite. Weathering affords a good number of secondary minerals, as carbonates quartz, iron ores, from the chloritized augite and biotite, serpentine from the olivine, and sometimes epidote and sericite. The orthoclase feldspar is sometimes microcline, and sometimes anorthoclase. It occurs in surface sheets and dikes. It contains 55–61 silica, with Gr. 2.61. The orthoclase crystals are sometimes two inches long. The carrying only these phenocrysts places this rock under the orthophyres; but

the chemical composition places only the more acid here, the main body belonging with the augite-syenite porphyries.

2. **KERATOPHYRE** (Gümbel).

A (*M*) compact groundmass resembling hornstone (whence the name), carrying very small phenocrysts of feldspar. (*m*) the groundmass is fine crystalline granular and composed mainly of feldspar, which somewhat resembles trachyte, and sometimes orthophyre. It has a variable quartz content which is (*M*) in the quartz variety.

Silica 61–66; Gr. 2.61.

QUARTZ-KERATOPHYRE (Lossen).

A similar rock containing a large amount of quartz in the groundmass and as phenocrysts in small number. The groundmass is coarser grained than in the basic variety. It occurs at Baraboo, Wis., like a lava, and associated with tuffs.

Silica 70–80; Gr. 2.64.

The basic variety occurs in the Fichtelgebirge, Harz, Nassau, and in New England (see below); the quartz variety in Saxony, Great Britain. Both are soda-orthoclase rocks, where the feldspar is sometimes a mixture of both orthoclase and albite, and sometimes microperthite. The phenocrysts are variable from few to abundant. In the groundmass appear also (*m*) grains of magnetite, folia of brown mica, and specks of hornblende. (See under "Quartz-porphyries" p. 141).

(*a*) *Bostonite* (Hunter and Rosenbusch). From Marblehead Neck, Mass., Chateaugay Lake, N. Y., the Champlain valley; Montreal, Canada, Norway, Brazil, as basic keratophyre in dikes. It is a light-colored rock, with rough trachytic feel on a fracture, carrying phenocrysts of orthoclase, while the groundmass carries the same with anorthoclase. It is

essentially a feldspathic rock, without black bisilicates, and carrying (Norway) 61 silica. Brögger's exhaustive study of the associated bostonites and comptonites of Gran, Norway, conclusively shows that they are differentiations from a gabbroitic magma, and extrude sometimes at the same time and in the same dike, where each is at times the envelope of the other, and he suggests for these and similarly differentiated rocks the term "complementary," and states that they should be classed with the rock-form of the undifferentiated magma.

IV*b*. SYENITE-PORPHYRY.

A (*M*) fine-grained to compact groundmass without base, and carrying phenocrysts of orthoclase, hornblende, mica, and augite at the same time, the first predominating.

The groundmass is always crystalline-granular and composed of the minerals noted above, and with feldspar greatly predominant. They weather to chlorite and carbonates. As accessories are titaniferous magnetite, titanite, apatite, and zircon. In the augitic variety olivine is also accessory. They occur in dikes, and are distinguished from similar dioritic porphyries by their color, their freedom from amygdaloidal states, and their having orthoclase, which gives a potash rather than a lime-soda result to the chemical analysis. Quartz may be sparingly present without placing the rock among the quartz-porphyries. As varieties:

1. **Hornblende**-syenite-porphyry. A rock found in dikes and sheets, of compact groundmass, and carrying phenocrysts of orthoclase and hornblende. The groundmass shows usually all the syenitic minerals, and the black bisilicates weather to chlorite, epidote, and calcite. This changes the fresh brown or reddish-brown rock to green or grayish green. It contains 61 silica, and occurs in the Vosges, Tyrol, and Black Forest.

2. **Biotite**-syenite-porphyry. A dike-rock of limited extent in the southern Vosges, Sweden, Portugal. It is deep reddish brown when fresh, and chloritizes to greenish shades. Augite generally accompanies the biotite, and more or less plagioclase the orthoclase.

3. **Augite**-syenite-porphyry. A similar occurring rock from Brazil, the Caucasus, Montenegro, Spain, Albany, N. Y. The groundmass is greenish gray, and composed of large proportions of plagioclase with the orthoclase, augite, magnetite, pyrite, and altered olivine. The phenocrysts are usually large orthoclases and augites. The latter is usually dark green, but at Albany, N. Y., it is violet-brown and accompanied by a bluish amphibole. Olivine appears sparingly.

V. **COMPACT SYENITE** (Kalkowsky), Microsyenite (Wadsworth), Syenite-aphanite (Zirkel).

A compact mixture of syenite minerals (sometimes fine-granular), of dark greenish gray color, in narrow dikes, and bearing to syenite the same relation that felsite does to granite. It is usually weathered and the black bisilicates cloritized (which accounts for the color), and calcite is sometimes primary and sometimes secondary. This is distinguished from syenite by the failure to detect by the naked eye the syenitic minerals; but the lens and microscope show them. The fineness of the grain is peculiar to dike-rocks and the peripheries of larger masses where the walls are somewhat heated, so that cooling is not instantaneous, but more rapid than in the center of large masses. Wadsworth's microsyenite is the parallel of Rosenbusch's microgranite of similar rate of cooling. Aplite is of like origin. This may be taken as the groundmass of the above syenite-porphyries, and is associated with syenites and syenitic mica-traps.

There is no syenite glass.

GROUP 5. PHONOLITE.

PHONOLITE-ELÆOLITE-SYENITE EXTRUSIVES.

(Necessary minerals: An alkali feldspar, elæolite, or nepheline, and hornblende.)

PHONOLITE (Klaproth), Clinkstone.

A (*M*) compact groundmass which, in its fresh state, is dark greenish or yellowish gray, showing sporadic individual cleavage surfaces of sanidine. The mass shows a great tendency to fracture like slates and schists, or is thin tabular-jointed. Under these conditions it gives a clear sound when struck with a hammer (whence the name). On weathering a sharply defined yellowish-white or white crust is formed. (*m*) it is a compound of sanidine and nepheline (or leucite), with essential nosean (or haüyne), monoclinic pyroxene, hornblende, magnesia-mica rarely, and still more rarely plagioclase. The last seems to be restricted to trachytic phonolites poor in nepheline. This is divided into:

(*A*) **TYPICAL PHONOLITE,** or Nepheline-trachyte (Zirkel).

A compound, as above described, of sanidine and nepheline, with the other minerals as accessories only.

Silica 50–62; Gr. 2.4–2.65.

Phonolite occurs generally in isolated and precipitous dome-shaped masses of large size (Fernando do Noronha), as surface sheets of great extent, as lava-flows, and in dikes. It is found in Great Britain, Germany, Bohemia, central France, northern and eastern Africa, Cape Verdes, Canaries, Asia, Paraguay, Brazil, the Black Hills, and (in loose blocks) in Pasolty County, Col. The sanidine is (*m*) in the groundmass and (*M*) as large tabular phenocrysts,

with the clinopinacoid parallel to the cleavage plane, and with twinning after the Carlsbad type. Anorthoclase occurs (*m*). Nepheline is generally (*m*); but it is (*M*) in some Bohemian types, and in New Zealand it occurs in reddish phenocrysts one-half by one-fourth of an inch in size. Nosean is (*M*) occasionally, and haüyne rarely; the latter has been noted 3–4 mm. long. Sodalite (which has been mistaken for the latter) is sometimes 2–3 mm. long. Plagioclase is very irregular in this variety. Hornblende is common in (*M*) black needles that do not change to chlorite or epidote. Large augite phenocrysts are infrequent, but sometimes 7 mm. long. Part of these approach ægirite, which occurs (*m*). Great brown folia of magnesia-mica occur sparingly in a few localities. Magnetite is constant, but (*m*). Honey-yellow titanite (also yellowish red) is abundant (*M*); also zircon 1–2 mm. long. Olivine is wanting as a characteristic mineral; but occasionally it is found, and sometimes 2–15 mm. long. Quartz and tridymite are scarce and (*m*). Zirkel states that the groundmass is of two kinds, a typical *phonolitic* and a *trachytic* state. The former is dark-colored, with greasy luster, compact and non-porous, except as small haüyne or nepheline crystals have been removed by weathering; with ready cleavage, and small phenocrysts, which are generally sanidine. The cleavage is less marked in the highly porphyritic states. The groundmass fuses bp. more or less readily to a yellowish or greenish glass, and gives water in the closed tube. This type is found in Bohemia, the Mittelgebirge, the Lausitz, Cornwall (Wolf Rock), central France, Teneriffe, and the Canaries. The groundmass, of *trachytic* habit, is cleavable with difficulty or not at all; luster sub-greasy; color generally light-gray or yellowish gray; of rough porous feel. In rare cases small phenocrysts of nepheline appear with plagioclase. This is found in the Rhone district and Bohemia, and must

be distinguished from the old so-called "trachytic phonolite," which had lost its cleavage from weathering. The groundmass is partly soluble in HCl, the soluble part being nepheline and zeolites, while the feldspathic part is insoluble. The specific gravity, and the percentages of soluble matter and of water, are inversely proportionate to the percentage of silica. The cleavable states generally split readily and in thin sheets, so that the rock can be used for slating (Cantal in central France). Whole mountains of phonolite are divided by joints one foot apart. It also separates into long prisms, but not with such regularity as in basalt. The cleavages seem to be parallel to the cooling surface, and the prisms perpendicular to the same. Phonolite weathers with a sharply defined grayish-white to yellowish-white crust, which at first adheres to the tongue. Zirkel states that the minerals are removed in the following order: magnetite, haüyne, sodalite, the glass base (if present), and nepheline. All form zeolites, which next go, and leave hornblende, augite, and sanidine. After the alteration of the bisilicates the feldspar kaolinizes after prolonged weathering, to form a gray or mottled clay. Other states are as follows:

(*a*) *Porphyritic Phonolite.* Though the rock is generally porphyritic, there is now and then a specially porphyritic state, as in Bohemia, the Rhone district, etc. It is a (*m*) fine-grained aggregate of phonolitic minerals, rich in hornblende, with either an abundance of large hornblende prisms (sometimes 5 cm. long), an aggregate of hornblende and titanite, or a mixture of light-yellow transparent titanite, black hornblende, mica, nepheline, and zircon, which is like the allied rock at Ditro.

(*b*) *Vesicular Phonolite* is reported from Blattendorf, near Haida, Bohemia.

(*c*) *Spotted Phonolite* is only a colored state due to local

decomposition, at Luschwitz, near Aussig, Bohemia; or to a more coarse agglomeration of the mineral ingredients in patches, as on one of the Cape Verdes.

PHONOLITE GROUP B. (Zirkel.)

Nosean-trachyte (Lenk), Haüyne-trachyte, Nosean-phonolite (Zirkel).

A variety of phonolite in which nepheline is replaced by nosean (haüyne), of a deep-black color, splintery fracture, thin jointed structure, and gray weathered state. The groundmass is compact, and shows (*M*) only sporadic long prisms of hornblende; but (*m*) exhibits sanidine, augite, magnetite, and abundance of minute nosean. Plagioclase and nepheline seem to be absent. It occurs in loose blocks at the Kreuzberg, Mont Dore, in northern Bohemia, in a dike at La Rochette, etc.

Taimyrite (v. Chrustschoff). From Taimyr Land, Siberia. An ophitic aggregate of nosean and anorthoclase, with accessory plagioclase, amphibole, biotite, melanite, magnetite, sphene, zircon, and glass. Anorthoclase is in long slender crystals and nosean abundant. Zircon is the only accessory of importance and is of trachytic type. Associated with this is a similar compound, except that sodalite replaces nosean, and that zircon is granitic. Gr. 2.57–2.62. The rock is nearly ophitic.

PHONOLITE GROUP C. (Zirkel.)

LEUCITE-PHONOLITE, Leucite-nepheline-trachyte (Zirkel), Leucitophyre (Rosenbusch).

A microcrystalline groundmass, with a small amount of glass, carrying phenocrysts of sanidine, leucite, nepheline, and haüyne (colorless, bluish gray to black, or, when weathered, white or reddish), hornblende, and no plagioclase nor olivine.

Silica 45–54; Gr. 2.5–2.9.

It is found in loose blocks, in plugs, in tuff, also in dikes near the lake of Laach, Rieden, Selberg, etc., in Bohemia, Italy, Persia, etc. The groundmass consists (*m*) of a small amount of glass base with an abundance of crystallized sanidine, leucite, nepheline, haüyne, augite, biotite, hornblende, titanite, apatite, magnetite, and melanite. Some occurrences are porous. By weathering calcite and zeolites appear, and analcite forms pseudomorphs after the leucite.

(*a*) *Nositc-melanite Rock* (vom Rath). A fine-grained to compact compound of leucite, nepheline, nosite, sanidine, black garnet (melanite), with some hornblende, pyroxene, and titanite. Contains silica 48–55; Gr. 2.7–2.9. This is a grayish dark-colored rock that frequently shows hyalite crusts, from the decomposition of the silicates it contains.

PHONOLITE GROUP D. (Zirkel.)

LEUCITE-TRACHYTE (vom Rath).

In a compact light-gray, bluish-gray, or dark-gray groundmass, with splintery fracture, occur fresh sanidine, white and somewhat decomposed leucite, blue haüyne, augite, mica, magnetite, and seldom titanite. The vesicular cavities are filled with (*m*) small nephelines.

Silica 60.

This occurs in a few places in Italy and Brazil in lava-

streams. The leucite appears to be as phenocrysts, and does not show in the groundmass to any extent. This latter is microcrystalline. The leucites are sometimes 10 cm.

(*a*) *Olivine-leucite-phonolite* (A. Hague). As detritus in the Ishawooa River, Wyoming, consisting of numerous phenocrysts of olivine and augite in a groundmass composed (*m*) only of leucite and an alkali feldspar, with a small showing of plagioclase and folia of biotite.

PHONOLITE GLASS.

As stated at the beginning of the rocks, the tendency to form hyaline states decreases with the lowering of the content of silica in a rock, and, at the same time, the tendency to crystallize increases. There may be numerous instances of glassy states of this rock, but, as yet, few have been noted. They have, probably, long since been removed by erosion, as phonolite is not found in very recent effusions.

Phonolite-pitchstone (Laube). Near Weipert is a brownish black rock, of pitchy luster and fluidal structure, in which are (*m*) numerous phenocrysts of sanidine, magnetite, and nepheline.

Phonolite-obsidian. As selvages to phonolite dikes and lava-streams in Teneriffe; in phonolite tuffs, and as volcanic bombs, with silica 73. It is black, gelatinizes with HCl, and gives crystals of NaCl. (*m*) it shows sanidine, ægirite, and haüyne, with chalcedonic nepheline.

Leucite-phonolite-pumice. In minute fragments in a tuff of this rock at the foot of the Olbrück. They show an almost colorless foamy glass with sharply defined (*m*) phenocrysts of leucite, augite, nepheline, rarely haüyne, magnetite, or titanite, and as the arrangement is the same as in the rock of the Olbrück, it is accepted as a true phonolite-pumice.

GROUP 6. ELÆOLITE-SYENITE.

PHONOLITE-ELÆOLITE-SYENITE INTRUSIVES.

(Necessary minerals: Alkali feldspar, elæolite, and hornblende.)

ELÆOLITE-SYENITE.

A compound of an alkali feldspar, elæolite (leucite, etc.), one of the black bisilicates, and no quartz.

Silica 43–68; Gr. 2.46–2.63.

This rock occurs in extended masses, bosses, laccoliths, and dikes, like syenite, and is also found in erratic blocks (probably distributed through glacial agencies). It is found in the Tyrol, Portugal, Pyrenees, Transylvania, southern Norway, Sweden, Lapland, Ilmen Mountains, Greenland, Brazil, Africa, the Cape Verdes, Great Britain, and in North America in eastern Ontario, and near Montreal, Canada; at Salem and Marblehead, Mass.; Red Hill, N. H.; Litchfield, Me.; Magnet Cove and elsewhere in Arkansas; Beemersville, N. J.; through the Champlain valley of Vermont; in New York; Trans-Pecos region, Tex.; Crazy Mountains, Mont., and Rocky Mountains of Canada. It occurs massive, schistose, and porphyritic, as follows:

I. Elælite-syenite.

(*a*) *Leucite*-elæolite-syenite.

(*b*) *Melanite*-elæolite-syenite.

II. *Monchiquite.*

III. Elæolite-syenite-*porphyry.*

(*a*) *Leucite*-elæolite-syenite-porphyry.

I. **ELÆOLITE-SYENITE,** Laurdalite (Brögger).

A generally light-colored granitoid compound, varying from medium fine-grained to irregular coarse-grained, of an orthoclase, amphibole, mica (mostly biotite), and pyroxene, with quartz almost always absent.

Average silica 53; Gr. 2.55.

This is a smutty red (*M*) compound of variable mixture;

at times regularly or irregularly coarse granitoid; at times trachytic from tabular minerals; at times with parallel arrangement of the minerals as in phonolite. Fluidal structures show (*m*). Orthoclase forms stout crystalline grains with Carlsbad twins (rarely of Baveno); often microperthitic. Sometimes microcline, anorthoclase, and cryptoperthite are present; also plagioclase in varying amount. Elæolite is generally idiomorphic with respect to feldspar, and occurs crystal, and in irregular grains of whitish, grayish, reddish color, and sometimes 2½ feet long. It alters to Ca-Na-zeolites and calcite. Melanite is sometimes found (*m*). Well-crystallized blue sodalite is common. Cancrinite is present as a primary and as an alteration product. Leucite is not present, but represented by analcite. Pyroxene is usually green and well-crystallized augite, which is sometimes epidotized; sometimes colorless malakolite is found in fine-grained rocks, sometimes ægirite in radial aggregates, sometimes both augite and ægirite together; brown acmite (at Beemersville, N. J.) occurs, to the exclusion of the others. Rosenbusch says that pyroxene sometimes fails entirely. Hornblende, as should be the case, is the most constant of the black bisilicates, and when two are together one is generally this mineral. It occurs green, brownish green (by transmitted light), and generally idiomorphic. It is usually a soda-hornblende, as shown by the flame. Ænigmatite sometimes occurs in long individuals. Mica is generally biotite (dark-brown magnesia-mica) in hexagonal tables and irregular folia; sometimes it is dark green. Lepidomelane occurs in black lustrous tables at Litchfield, Me. Nosean is found now and then. The common accessories, magnetite (ordinary and titaniferous) and apatite, are (*m*); calcite is common as secondary, zeolites less so; eudyalite (*M*) is rare; melanite, nosean, and wollastonite are (*m*) at Montreal; scapolite (*M*) in eastern Ontario; zircon is sporadic (the

so-called "zircon-syenite" of Norway is an elæolite-syenite rich in the mineral); olivine and pyrite sometimes occur. This rock seems to be a middle ground on which all the other varieties meet. The sporadic and scanty quartz, with orthoclase, sometimes causes a resemblance to granite: nepheline and leucite (also melanite), with an increase of plagioclase and the black bisilicates, ally it to the basic rocks; while a predominance of the latter minerals places it at their most basic end, as is shown by the great range of its silica content. We can distinguish

1. **Hornblende-pyroxene**-elæolite-syenite, where the two black bisilicates are equally predominant. The varieties are:

(*a*) *Foyaite* (Blum). From the mountains Foya and Picota in the province of Algarve, Portugal. A granitoid compound of orthoclase, elæolite, hornblende, pyroxene, and biotite. Orthoclase is prominent in white or grayish white elongated tables with imperfect twinning; plagioclase is accessory; reddish and weathered elæolite in hexagonal crystals; pyroxene (augite and ægirite) in green crystals; green hornblende, biotite in hexagonal folia. As accessories apatite and magnetite are constant and abundant; sodalite and titanite sporadic; melanite, tourmaline, and pyrite occasional; rarely cancrinite, epidote, or zeolites. The texture varies rapidly from fine to coarse, but the crystals are usually equidimensional. It is sometimes compact and porphyritic, but without base, and of ash-gray color. The content of black bisilicates varies greatly; generally pyroxene is predominant, sometimes it is alone; sometimes hornblende is alone, and sometimes accompanied by mica—all in the same mass. The Libertyville (N. J.) rock carries yellowish orthoclase two inches long, abundant elæolite, ægirite, and sodalite, while biotite is rare. Brögger gives this name to a trachytoid rock in Norway with a different com-

position. (Here would come the coarse-grained and trachytoid states of the Brazilian rock whose dike-forms are called *tinguaite* (Rosenbusch), as Hussak states that this rock is only a porphyritic state of foyaite. In the United States there is the same variation in the values of the hornblende and pyroxene content, as well as the same changes in structure of the principal mass.)

(*b*) *Cancrinite-ægirite*-syenite (Törnebohm). From the Siksjöberge, Sweden, in dikes and masses—the former are porphyritic. It consists of tabular feldspar (orthoclase, anorthoclase, microcline, and plagioclase), cancrinite in crystals $\frac{3}{4}$ inch and in irregular grains, in a (*m*) mixture of the same with elæolite, ægirite, titanite, and apatite. (See later under "Elæolite-syenite-porphyry.")

(*c*) *Sodalite*-syenite (Steenstrup). From Julianshaab district, Greenland. A light yellowish-gray, coarse-grained, miarolitic granitoid principal mass of greenish-white lath-shaped feldspar (microcline, $\frac{1}{8}$ inch long), black arfvedsonite (9 inches long by $3\frac{1}{2}$ inches thick), ænigmatite, ægirite (with submetallic luster), and sodalite (1 inch thick). Garnet, red eudialyte, and infrequent elæolite are accessory, and sometimes $\frac{1}{2}$ inch thick. Silica 56.45.

2. **Mica**-elæolite-syenite, Miascite (G. Rose). From Miask in the Urals. Composed of orthoclase (Breithaupt's microcline), white or gray; yellowish-white elæolite with subresinous luster; gray to blue sodalite; nearly equiaxial leek-green mica. As accessories, wöhlerite, zircon, ilmenite $3\frac{1}{2}$ by $2\frac{1}{2}$ inches, cancrinite, pyrite, monazite, quartz, hornblende, and pyrochlore. It is also found near Lake Superior. Silica 68.16.

(*a*) *Litchfieldite* (Bayley). From Litchfield, Me. It shows snow-white feldspar (orthoclase, albite, microcline), large yellowish cancrinite, dark-blue allotriomorphic sodalite, gray greasy elæolite (2 inches), black folia of lepidomelane,

and sometimes brown zircon. Hornblende, pyroxene, and titanite are absent. Silica 60.39.

(*b*) *Pulaskite* (J. F. Williams). From Pulaski and neighboring counties, Ark. A porphyritic compound of biotite, orthoclase, cryptoperthite, scanty elæolite, arfvedsonite, and diopside. The phenocrysts are orthoclase. Silica 60.03.

3. **Hornblende-mica**-elæolite-syenite, Ditroite. From Ditro in the Siebenbürgen in Transylvania. A coarse- to fine-grained rock—somewhat finer grained than miascite—with occasional compact and schistoid states. The parallel arrangement of sodalite adds to this last effect. It contains white orthoclase (weathering red), microcline, plagioclase, gray elæolite, large (1 inch) prisms of hornblende, usually altered to chlorite or biotite, blue sodalite, and usually cancrinite. Titanite and zircon are abundant accessories. Secondary products are muscovite, calcite, chlorite, epidote, and ferrite.

(*a*) *Zircon*-syenite. A variation of the last with abundant zircon. Where it has been described as a separate rock, it is a granitoid compound of orthoclase, microcline, elæolite, occasional sodalite, abundant zircon (red, brown, yellow), and scanty hornblende. It occurs in Norway, at Marblehead, Mass., etc. Silica 50–55; Gr. 2.7–2.9.

(*b*) *Endyalite*-syenite (Vrba). From south Greenland, composed of soda-orthoclase, much plagioclase, yellowish white elæolite, black hornblende, eudyalite (in blood-red grains 1 mm.), magnetite, apatite and small nests of mica.

I*a*. **LEUCITE**-elæolite-syenite (Hussak).

A coarse-grained variety from Serra de Caldas, Brazil, carrying analcite, which is pseudomorphed after leucite. A similar rock is found at Magnet Cove, Ark. There is no rock yet known where leucite entirely replaces elæolite, and where it remains unaltered.

I*b*. **MELANITE**-elæolite-syenite, Borolanite (Horne and Teall).

A similar rock in intrusive sheets and dikes near Lake Borolan, Assynt, Scotland (whence the name). A medium-grained mixture of soda-orthoclase and melanite (with pitchy luster) mixed with what is probably amorphous elæolite, green pyroxene, dark biotite, and a sodalite mineral. Some varieties of the mass have little or no melanite, but consist of feldspar and pyroxene.

(*Schistoid* Elæolite-syenite. This is not a variety, but a state, of this rock which is found in many localities—notably at Ditro, near Christiania, and in Greenland, and is due to the parallel arrangement of the minerals, especially the black bisilicates. There are also lenticular concretions, which make "pudding" varieties of the various rocks. These latter are caused (as in granite) by aggregates of feldspar and elæolite with some of the black bisilicates.)

II. **MONCHIQUITE** (Hunter and Rosenbusch).

A dike-rock associated geologically and mineralogically with the elæolite-syenites, and having a distinct facies. It is a porphyritic combination of augite and olivine, with a glassy base, with which may be associated either hornblende or mica (or both together). The base includes (*m*) phenocrysts of plagioclase and occasionally of nepheline. The rock is black or grayish black when fresh, and weathers sharply to brown. It gelatinizes slightly in cold, readily in hot, HCl. This and its greasy luster are indications of nepheline.

Silica 43–47; Gr. 2.8–3. Rosenbusch divides the species thus:

1. With olivine;

(*a*) and augite, *monchiquite;*

(*b*) and augite and amphibole, *amphibole*-monchiquite;

(*c*) and augite and biotite, *biotite*-monchiquite;

(*d*) and augite, amphibole, and biotite, *amphibole*-biotite-monchiquite.

2. Without olivine.

The combinations (*a*), (*b*), etc., are as just stated.

(*a*) *Fourchite* (J. F. Williams).

(*b*) *Amphibole*-fourchite (Rosenbusch).

(*c*) *Ouachitite* (Kemp).

(*d*) *Amphibole*-ouachitite (Rosenbusch).

The name comes from the Serra de Monchique, Portugal, where the first of the type was found. These rocks are an entirely (*m*) series, and cannot be told in many cases from basalt, except by their brown weathering. This and the gelatinization with HCl afford some chances of detection (*M*). In the United States are found

Fourchite (Fourche Mountains, Ark.; Beemersville, N. J.; Essex County, N. Y.; Lake Memphremagog, Vt.; Angel's Island, San Francisco Bay, Cal.). Silica 47.

Ouachitite (throughout Arkansas, Beemersville, N. J.). Silica 36.40.

Monchiquite (in the Lake Champlain region of Vermont).

PORPHYRIES OF THE ELÆOLITE-SYENITE GROUP.

III. ELÆOLITE-SYENITE-PORPHYRY.

A more or less compact groundmass, like hornstone, with subconchoidal or splintery fracture; greasy luster; color light or dark green; carrying phenocrysts of feldspars, elæolite, and sodalite.

Silica 44–56; Gr. 2.55.

It occurs mainly massive and in dikes, associated with

the crystalline states. It is found in the Tyrol, Greenland, Norway, Brazil, Portugal, Scotland, Montana, Beemersville, N. J. It bears to elæolite-syenite the same relation that quartz-porphyry does to granite.

1. **Liebnerite-porphyry.** From the southern Tyrol.
   Gieseckite-porphyry. From Greenland.

In weathered dikes. A flesh-red to brown groundmass (from ferrite) carrying (*m*) tabular brick-red, Carlsbad-twinned orthoclase phenocrysts, and ⅛-inch prisms of greasy oil-green to bluish green liebnerite (geiseckite). This latter is a micaceous secondary product from elæolite. Silica, 44.66.

2. **Hornblende-pyroxene**-elæolite-syenite-porphyry.

(*a*) *Tinguaite* (Rosenbusch). Dike-rocks from the Serra de Tingua, Brazil, similar to *foyaite*. Hussak states that these have a gneissoid habit.

3. **Nepheline-rhomb-porphyry** (Brögger). In a dike from elæolite-syenite in southern Norway, with 56–57 silica. A somewhat dark-grayish to violet rock with (*m*) fine-grained groundmass carrying large phenocrysts of soda-orthoclase and microperthite. The groundmass (*m*) shows nepheline. It cannot be distinguished from rhomb porphyry by the naked eye, but HCl reactions will show difference.

III*a*. **LEUCITE**-elæolite-syenite-porphyry. From Serra de Tingua, Brazil, and with pseudomorphs of analcime after leucite—like the granular rock.

(Some authorities note a *leucite-syenite*-porphyry containing sanidine and what appear to be minute (*m*) orthoclases in the groundmass, on the ground of its being a Silurian extrusion, and state that it would be a *phonolite* if it had been extruded as late as Tertiary times. As there is no good reason for dividing rocks according to geological age, this rock is a phonolite, no matter whether it belong to pre-Cambrian or recent times.)

INTERMEDIATE DIVISION.

II. ALKALI-LIME-SODA SECTION.

MICA-TRAP INTRUSIVES.

(Necessary minerals: Feldspar, black bisilicates.)

MICA-TRAP ROCKS (v. Cotta), **LAMPROPHYRES** (Rosenbusch).

Naumann first used the name "mica-trap" for a rock in the Erzgebirge, which he afterwards identified with the "minette" of the miners of the Vosges, and in 1838 abandoned the old name. The name signified a rock with predominant mica that resembled "trap" in its jointing and weathering. In his treatise on lithology v. Cotta refers to the above and says: "Under the circumstances it may be admissible to transfer the name of mica-trap to an entire group of similar rocks, whose common attributes are that they consist principally of compounds of mica and feldspar, without marked porphyritic texture, and that they contain no quartz, unless quite exceptionally. We count in this group the following rocks (although it is uncertain if they all are of igneous origin), viz., minette, fraidronite, kersanton, and kersantite. Until that question is determined in the negative they may be so classed on account of their petrographic affinity; and for the same reason they will be most conveniently treated as varieties of the same rock."

Eight years after this was issued Gümbel described his *lamprophyre*, and twenty-one years after the same date Rosenbusch gathered the above rocks into the class of

"lamprophyres," which differed from the original "diabase like" rock of Gümbel in having orthoclase as one of the constituents. It was at once seen that these rocks could not be united under the present system of mineral compounds, and the "syenitic" and "dioritic" divisions of the lamprophyres followed. Zirkel discards the later name entirely, and places minette with the syenitic porphyries, and the other three under the diorites. All of them show to a considerable degree the columnar and tabular jointing and spheroidal weathering of basalt, the original "trap"; and as both v. Cotta and Rosenbusch think them worthy of a separate classification, they should be called by the older name. The variation in their feldspars, however, requires that they be placed under the syenitic and dioritic groups, as there is no good reason for separating dike-rocks from other eruptives. The original lamprophyre of Gümbel was placed by him with the mica-traps (minette, kersantite, kersanton, and mica-diabase), and the name "shining" refers to the mica content. If it be proper to annex to this group a rock like vosgesite, which is conspicuous for having little mica, it is a matter of little consequence whether the name of the group be "lamprophyre" or "mica-trap," as long as both refer to the same mineral. The lamprophyres of the Shap granite mass in England are shown by their containing the same quartz, orthoclase, and sphene to have originated in the same magma as the granite by differentiation.

These rocks may be imagined to be granite-porphyries poor in quartz and rich in black bisilicates. They can be divided according to their feldspar:

I. With an alkali feldspar, *syenitic* mica-trap.

II. With plagioclase, *dioritic* mica-trap.

GROUP 7. SYENTIC MICA-TRAP.

I. SYENITIC MICA-TRAP, Syenitic Lamprophyre (Rosenbusch).

A series of porphyritic rocks (and also porphyries) having a (*M*) fine-grained to compact groundmass of orthoclase and plagioclase in needles, with the other syenitic minerals highly predominant, and carrying some or all of them as phenocrysts. Biotite is always present in the groundmass and usually as phenocryst. They can be taken as intermediate between the syenites and their porphyries.

Silica 48–65; Gr. 2.5–2.9.

These are a series of dike varieties of mica-syenite, or states that have cooled under similar circumstances, and they differ from the mica-porphyrites in the state of the matrix and the fact that the mica is in folia rather than in tabular crystals. They are characterized by columnar and tabular jointing, by spheroidal weathering, and by resistance to disintegration. They carry as accessories magnetite, pyrite, abundant apatite, and the derivatives of their components. Under this head will be grouped:

I. Minette (orthoclase and predominant biotite).

II. Vosgesite (Rosenbusch), (orthoclase, hornblende, and augite).

I. MINETTE (old mining name; first noted by Élie de Beaumont).

In a matrix usually coarse enough to be resolved by the lens (generally fine crystalline and porous, with dark-gray color [also reddish to blackish-brown]); composed of orthoclase and much mica with some hornblende, are abundant folia of biotite, with occasional phenocrysts of orthoclase, olivine, and hornblende.

Silica and gr. as above.

It was named first in the Vosges. It also occurs in

Saxony, Bohemia, France, Jersey, Great Britain, and Scandinavia. The orthoclase is flesh-red; mica brown to black —seldom green; hornblende grayish to dark green. On the selvages of the dikes and wherever quickly cooled it becomes compact. The folia of mica are sometimes nearly half an inch across; the feldspar weathers to pinite and kaolin in the groundmass, and is seldom fresh. Calcite and siderite are also secondary products. Chlorite sometimes occurs; quartz never.

(*a*) *Hornblende*-minette, with predominant hornblende, occurs in Alsace, Erzgebirge, the Auvergne, etc.

(*b*) *Augite*-minette, with predominant augite, occurs in the Vosges, Fichtelgebirge, Sweden, England.

(*c*) *Fraidronite* (E. Dumas) is a similar rock, much weathered, from France in a limited number of localities (departments of the Lozère, Cevennes, etc.). It is of dirty green color, with weathered felsitic mass carrying much mica, with pyrite and quartz as secondary products; also calcite and siderite in veins and included balls. The rock is highly fissile when weathered. The above rocks are variations between mica-syenite and mica-syenite-porphyry.

II. **VOSGESITE** (Rosenbusch).

In a grayish-brown, greenish-gray to black groundmass of similar structure to minette, composed of abundant and generally (*m*) orthoclase and other syenitic ingredients; but showing phenocrysts of only hornblende and augite. A quartz-free syenite-porphyry with predominant hornblende and augite.

Silica 48; Gr. 2.93.

It occurs in narrow dikes in the Vosges, Erzgebirge, in Brazil, and (augite-vosgesite) at Livermore Falls, N. H. The rock weathers like the syenites to a reddish or rusty brown color, and is the parallel of minette, with biotite replaced by the other two black bisilicates. These are so predominant

in certain localities that Rosenbusch has divided the rock into amphibole- and augite-vosgesite. The former bears to the hornblende-syenite-porphyry and hornblende-syenite the same relation that the latter does to the augite varieties of the rock. In both plagioclase appears with orthoclase; hornblende is in thin and augite in stout prisms. Uralite sometimes appears. Orthoclase and biotite seldom appear as phenocrysts. The orthoclase is rich in soda. This rock is decidedly more like "trap" than minette, from its color and higher gr. Holocrystalline and porphyritic textures occur in the same dike.

GROUP 8. DIORITIC MICA-TRAP.

II. DIORITIC MICA-TRAP, Dioritic Lamprophyre (Rosenbusch).

A series of dioritic compounds too decidedly porphyritic to be classed as typical diorites, and too granular to be placed with the diorite-porphyrites. Their peculiar texture is observed in dike-rocks and masses that have cooled against moderately hot walls. Their hornblende is usually basaltic and rod-shaped, their magnetite content is good, and they may have abundant augite. Rosenbusch has distinguished:

1. Kersantite, which is intermediate in texture between mica-diorite and mica-porphyrite.

2. Camptonite, which is intermediate between the hornblende varieties of the same, but both Zirkel and M.-Levy have relegated the latter back to diorite, as there is no good reason for its separation. This leaves kersantite and its varieties where v. Cotta placed them.

1. **KERSANTITE** (Delesse).

A porphyritic rock, rarely so fine-grained as not to be resolved by the lens, with a principal mass composed of oligoclase (or oligoclase and biotite) and orthoclase (and sometimes sanidine), and carrying phenocrysts of oligoclase, laminæ of biotite, fibers of hornblende, green augite, and some quartz, olivine, and magnetite.

Silica 49–57; Gr. 2.62–2.86.

It occurs in narrow dikes, which sometimes are like surface sheets, in Silesia, Thuringian Forest, Alsace, Austria, Bretagne, and Great Britain. The rock is holocrystalline without base. The oligoclase phenocrysts are striped brown, green, red, etc., from decomposition products. They vary from rod shapes in the fine-grained states to stout ones in those of coarser grain (in some cases over an inch long). Biotite (or anomite) laminæ are sometimes nearly half an inch across, and the mineral is abundant in the principal mass as in minette, and on the selvages it is parallel to the dike-walls. Pyroxene is usually green augite, also enstatite and bronzite, which latter alter to bastite. Hornblende is the brown basaltic kind, rod-shaped and sometimes $\frac{1}{8}$ inch long; uralite is rare. Quartz occurs as in granite, and sometimes forms micropegmatite with orthoclase. Now and then it is an inch across. Quartz, orthoclase, and oligoclase also occur as secondary minerals, with calcite and (rarely) epidote as alteration products. Pyrite, pyrrhotite and garnet also occur. In some localities are lenticular concretions of mica, also of chlorite, quartz, and reddish calcite.

(*a*) *Kersanton* (Rivière). A rock which the microscope has shown to be kersantite, so that the name is now abandoned.

(*b*) *Aschaffite.* Some authorities place this rock here. (See under "Granite-porphyry.")

(*c*) *Olivine*-kersantite (Rosenbusch). Here olivine is abundant enough to attract attention. From lower Austria.

(*d*) *Quartz*-kersantite (Barrois). In small massives and a dike in Spain. A bluish green dense groundmass (also fine-grained) carrying large phenocrysts of plagioclase, biotite, and quartz. Seldom granitoid or wholly dense. Secondary calcite, chlorite, epidote, and muscovite occur.

(*e*) *Pilite*-kersantite (Becke). Poor in mica and rich in augite, the former having chloritized. Of rare occurrence.

GROUP 9. PORPHYRITE AND MICA-PORPHYRITE.

IIb. ALKALI-LIME-SODA SECTION.

(Necessary minerals, plagioclase, mica.)

I. PORPHYRITE, Plagioclase-porphyrite.

A rock with a compact matrix of plagioclase and carrying phenocrysts of feldspars, with few or no phenocrysts of the black bisilicates; occasionally of quartz.

Silica 59–68; Gr. 2.6–2.7.

II. MICA-PORPHYRITE.

A similar rock carrying abundant phenocrysts of mica, and also of feldspar, hornblende, and infrequently of pyroxene.

Silica 60–67; Gr. 2.6–2 7.

A *porphyrite*, in distinction from a *porphyry*, is a rock with a matrix of plagioclase rather than of orthoclase. Both rocks contain both feldspars; but in the porphyry the alkali form predominates and the quartz content is high: in the porphyrite the Ca-Na-form predominates and quartz is

rare (either in the groundmass or as phenocryst). The old distinction between the two rocks on the score of the presence or absence of quartz as phenocryst or in the mass is no longer held. As the phenocrysts are predominant plagioclase, mica, hornblende, or pyroxene, the porphyrite is called plagioclase-, mica-, hornblende-, or pyroxene-porphyrite. Zirkel classes all except the pyroxene varieties under "diorite-porphyrite." The first two types (plagioclase and mica) will be treated here. The groundmass varies alike in both, and the phenocrysts are similar. After a general description they will be further noted apart. They occur mostly in thin dikes; intrusive sheets; as bosses and in tuffs. They are also frequently found as old extrusive sheets of great thickness, so that they partake of both extrusive and intrusive characters. They therefore show stretched vesicular structures, both empty and filled with green earth and calcite, which frequently form the greater part of the mass. The masses are irregularly jointed and fissured; rarely columnar and tabular. They are less widespread than the quartz-porphyries, and do not form such large masses. They are found in Saxony, the Harz, Black Forest, Vosges; in Belgium, Bohemia, Tyrol, Italy, Montenegro, Spain, Asia, Africa; in the Augusta Mountains, Nev.; New Hampshire, Vermont, New York, and Canada. The porphyrites will be separated from melaphyre by the olivine content of the latter; so that both are plagioclase-porphyries (using the term in its general meaning); porphyrite being without, and melaphyre with, olivine. As in all mixtures there are points where several minerals seem to be equally predominant, and where the rock is a transition between two types. There is also the point where the black bisilicates retreat into the groundmass and only plagioclase shows. Here the microscope must decide as to the variety, unless either quartz or orthoclase appear, and then

it will belong to the micaless porphyrites. All types of porphyrite with no (or few) phenocrysts of black bisilicates will be grouped under porphyrite. Three types of groundmass are given for the purpose of making clear some of the following divisions, though the types can only be distinguished (*m*).

(*a*) Greenstone-like porphyrite. With a (*m*) crystalline groundmass like diorite, green through chloritization or formation of epidote from hornblende; greenish hornblende, also green by transmitted light; dirty greenish white feldspar; biotite not very dark; little or no base. It forms as a rule bosses from which dikes run into the older schists, and makes what may be extrusive as well as intrusive sheets. Most of the hornblende- and mica-porphyrite dikes in central Tyrol, beds in the Alps, dikes in the Falkenstein, in Sweden, Belgium, etc., are examples of this type.

(*b*) Andesitic-porphyrite. (*m*) like andesite, with gray, grayish black, brownish black color; fresh and almost glassy plagioclase; hornblende brownish black and brown in section; biotite very dark; not much quartz; groundmass rich in ferrite and with andesitic structure, sparingly microdioritic; with small amount of glass base (colorless, yellowish, grayish). Found in the Thuringian Forest, Saar-Nahe district, etc., as dikes.

(*c*) Porphyry-like Porphyrite. (*m*) like the porphyries and sometimes micropegmatitic and microfelsitic; color reddish, brownish red; or chestnut-brown (from ferrite); poor in black bisilicates; richer in silica than (*b*); quartz quite abundant as (*M*) phenocrysts and in the groundmass; in many cases the groundmass is (*m*) compact. In Alsace, Silesia, Altai Mountains, Saar-Nahe district, as dikes.

Plagioclase phenocrysts are white, yellowish white, or reddish white, and usually somewhat altered and dull. They are oligoclase, sometimes andesine, less frequently

labradorite. When hornblende is present it is as stout prisms or acicular shapes of brownish black color. Biotite occurs in regular hexagonal tables, sometimes in prisms, rarely in folia. Quartz occasionally appears in large phenocrysts, as do orthoclase and garnet. Augite is now and then (*M*).

I. **PLAGIOCLASE-PORPHYRITE,** Porphyrite.

In a groundmass with a habit like that described in (*c*) are phenocrysts of plagioclase (usually oligoclase, frequently andesine, less so labradorite), and sometimes orthoclase and quartz.

Silica 60–68; Gr. 2.6–2.7.

It occurs in the Black Forest, Bohemia, Scotland, Altai Mountains, Ecuador. The groundmass is gray, red, violet, or blue, in which the phenocrysts are well contrasted. In the Rothliegenden formation of Germany it is found in a thick extrusive sheet.

II. **MICA-PORPHYRITE.**

A groundmass as above, with predominant phenocrysts of biotite and plagioclase, also orthoclase and quartz.

Silica 60–67; Gr. 2.5–2.8.

This is found in Saxony, the Thuringian Forest, Saar-Nahe district, central Alps, etc. Kemp reports an augite-mica-porphyrite in bosses west of Deckertown, N. J.

1. **Quartz**-mica-porphyrite.

A porphyrite with light green tabular plagioclase phenocrysts; dark biotite tables (more frequently in folia than in the quartzless varieties); rounded grains of quartz and sometimes double pyramids; frequently orthoclase $\frac{1}{4}$ inch long. The groundmass is a (*m*) aggregate of angular quartz and feldspar prisms. Silica 62–78; Gr. 2.74.

It occurs in dikes and is found in Alsace, Austria, the Alps, etc., and from Gippsland, Australia, a variety with the high silica content of 72–77.66 is reported.

(*a*) *Malchite* (Osann), from the Melibocus, as a dike-rock of the diorite group, with silica, 63.18. The dense groundmass carries rare phenocrysts of dark biotite, pale green labradorite, and quartz; with (*m*) green hornblende, sphene, and allanite.

INTERMEDIATE DIVISION—LIME-SODA SECTION.

GROUP 10. DACITE.

IIIa. DACITE QUARTZ-DIORITE EXTRUSIVES.

(Necessary minerals: Plagioclase, hornblende, and quartz.)

DACITE (Stache), Quartz-hornblende-andesite.

Named from the old Roman province of Dacia, where it was first found. The rock will be considered as always showing free quartz either (*M*) or (*m*), though Zirkel classes all rocks of similar mineral content with the average of silica of the quartzose varieties as dacite, whether they show free quartz or not. On the other hand, Rosenbusch includes quartzose augite-andesites. As Lang has shown that bulk analyses are of no value, and as the original rock was required to show free quartz, it will be so considered.

This group comprises:

I. Dacite.
II. Mica-dacite.
III. Pantellerite.
IV. Dacite glass.
V. Pantellerite glass.

I. **DACITE** (Stache).

A somewhat lighter-colored groundmass than that of hornblende-andesite, which shows large phenocrysts of glassy (sanidine-like) plagioclase, much hornblende, biotite, quartz, and sometimes sanidine.

Silica 62–72; Gr. 2.5–2.6.

It occurs as surface sheets and lava-streams, as dome-shaped hills, and as dikes, associated with hornblende-andesite. It is found in Germany, Hungary, Iceland, Armenia, Japan, Mexico, South America, New Zealand, and abundantly in the western United States in the Great Basin. The rhyolitic variety of groundmass is distinguished from that of rhyolite with great difficulty, as the plagioclases have (even (*m*)) the habit of sanidine, and only the greater silica content can settle the question. This is the case with the American dacites (Zirkel). The plagioclase is usually andesine; oligoclase, labradorite, and anorthite follow in decreasing importance. Quartz is (*M*) in round grains and in sharp-angled double pyramids (¼ inch long in Java), between dark and bluish gray, in some cases yellow or rose-red. In many varieties the quartz is only as phenocrysts. Hornblende and biotite often replace one another. The former is usually brown and alters to viridite and calcite. In some intances biotite alone appears. Augite is not abundant either (*M*) or (*m*). The (*M*) accessories are zircon, orthite, cordierite, and red garnet. Olivine is usually absent. An increase in sanidine makes this a trachyte, and a failing in quartz (or in the silica content) a hornblende-andesite.

(*a*) Timazite (in part). The more acid varieties of timazite (plagioclase, gamsigradite, mica, magnetite, and quartz) with silica 67.4 belong here. It is also found in the Vosges.

II. QUARTZ MICA-ANDESITE, Mica-Dacite.

This bears to dacite the same relation that mica-andesite does to hornblende-andesite.

III. PANTELLERITE (Foerster).

Rosenbusch calls this a transition between the "dacites" (using the term for all quartz-andesites) and the rhyolites, from its high silica content. It forms extensive lava-streams in the island of Pantelleria, which have at times a trachytic and a rhyolitic facies, with a third which is a mean between them. The groundmass is rich in iron and carries phenocrysts of plagioclase, anorthoclase, triclinic amphibole (cossyrite), ægirite-like augite, and no quartz, tridymite, or biotite. The "trachytic" groundmass has a web of feldspars and augite needles. The "rhyolitic" groundmass has considerable glass base and carries the same minerals. It contains silica 66.8–72.5; Gr. 2.6. Some authorities style it a pitchstone-porphyry with a granular groundmass.

(*a*) *Volcanite* (Hobbs). From Volcano, Italy, in bombs. A rock with glass base and groundmass of anorthoclase, andesine, acmite, and olivine, carrying phenocrysts of the minerals, and with silica 66.99. In structure and composition this is an augite-pantellerite.

IV. DACITE GLASS.

This weathers by changes occurring along the perlitic cracks, and working inward till the whole mass is white and opaque, and soft enough to be scratched by the finger-nail. When put into cold water it breaks into small fragments which fall to powder. By levigating this the unweathered feldspar phenocrysts can be secured intact.

(*a*) **Dacite**-felsite. Although this is not a glass, it is probably a devitrified one, and runs readily into perlite. It occurs at Arran, Scotland.

1. *Blue Porphyry.* At Mt. Esterel, department of Var, France. Silica 69. A (*m*) microfelsitic mass carrying phenocrysts of andesine (3 mm.), abundant sanidine, and acicular hornblende. Zirkel puts this as rhyolite from its high acidity, but chemical analyses are uncertain guides, and some dacites have been reported with still higher silica content.

(*b*) **Dacite**-pitchstone-porphyry. From Arran. A black rock readily breaking into spheroids when struck with a hammer. These are momentarily bright, but immediately cloud with a whitish film, which is considered to be caused by relief from strain and corresponding molecular change.

(*c*) **Perlitic** Dacite. From Mitake, Japan; Colombia, Ecuador. A dacite glass carrying (*m*) phenocrysts and perlitic globules—some 3 mm. In one case the dacite lava-stream had a layer of perlite crusted with pumice.

(*d*) Dacite-**obsidian.** Is reported in Hungary, Cabo de Gata, Ecuador, Italy.

(*e*) **Perlitic** Dacite-**pumice.** Containing spherules and phenocrysts, from northwestern South America.

(*f*) Dacite-**pumice.** From the west coast of South America. In some cases the phenocrysts are quite large. Quartz is 1–3 mm.

V. Pantellerite Glass.

A third variety of pantellerite (see p. 184) is a highly glassy base with a few microliths of augite and cossyrite, and carrying phenocrysts of plagioclase, augite, and cossyrite.

A fourth variety comprises the following states: obsidian, obsidian-porphyry, porphyritic pumice, pumice.

GROUP II. QUARTZ-DIORITE.

IIIa. DACITE-QUARTZ-DIORITE INTRUSIVES.

(Necessary minerals : Plagioclase, hornblende, and quartz.)

QUARTZ-DIORITE.

A diorite carrying either (*m*) or (*M*) free quartz. This can be divided into :

I. *Quartz-hornblende*-diorite.
II. *Quartz-mica*-diorite.
III. *Quartz-hornblende*-porphyrite.
IV. *Quartz-mica-hornblende*-porphyrite.
V. *Diorite-glass.*

I. QUARTZ-HORNBLENDE-diorite.

A coarse- to fine-grained crystalline-granular compound of Ca-Na-feldspar (frequently (*m*) orthoclase), hornblende, grayish-white quartz, and the other minerals more fully given under diorite; of dark-blue, blackish green, sometimes light-brown color. The minerals are as given under diorite (*q. v.*), except that quartz is always present. It occurs in rounded and angular grains, generally (*M*), rarely in double pyramids in the granular states.

Silica 55–67; Gr. 2.6–2.9.

It occurs like diorite, and is found with it, and especially in the Black Forest, the Vosges, the Odenwald, Servia, Bohemia, France, Belgium, Scotland, Hungary, Spain, Portugal, and at Cortlandt, N. Y. In the Andes quartz 6–8 mm. occurs. V. Cotta's *banatite* is a quartz-diorite in part, and part diorite, with andesine. The anorthite-diorite of Corsica has quartzose varieties. Orthoclase and quartz form micropegmatitic textures.

II. **QUARTZ-MICA**-diorite, Tonalite (vom Rath).

A fine-crystalline-granular compound of oligoclase, orthoclase, quartz, blackish-green hornblende, and brown mica.

Silica 66–70; Gr. 2.7–2.9.

It forms the principal mass of the Adamello Mountains in southern Tyrol and is named from the Tonale Pass. It also occurs in France, Saxony, Mexico, Australia, Japan, St. John, N. B., and in the Highlands of Scotland it grades on the one hand into quartz-diorite, and on the other into hornblende-granitite. Oligoclase is snow-white and contains but 57 per cent of silica; quartz is one-third of the mass in grayish grains; hornblende and mica are in small amounts—the hornblende in stout prisms (sometimes one foot long), and the mica in irregular folia. As accessories are orthoclase (which forms pegmatite (*m*) with quartz), zircon, garnet (an inch in diameter), sphene, titanite, magnetite, pyrite, and corundum. It was once called a granite. In some specimens primary concretions occur of dark mica and hornblende, with but little feldspar and no quartz, and the Japanese rock abounds in acicular tourmaline. Garnet is common.

III. **QUARTZ-HORNBLENDE**-porphyrite.

For the varieties of groundmass in diorite-porphyrite see p. 179, as well as for the predominant minerals. The presence of quartz phenocrysts is necessary to form this variety.

Silica 50–65; Gr. 2.6–2.7.

(*a*) *Black Porphyry.* From near Lugano, Italy. A light-gray to dark-green or dark-red groundmass with predominant feldspars, chloritized hornblende prisms, sporadic mica folia, and quartz.

(*b*) *Amygdalophyre* (Jenzsch). From near Dresden as sheets and tuffs. The groundmass is greenish brown and somewhat transparent on thin margins. As phenocrysts are feldspar and hornblende. The former is altered, the groundmass chloritized, but shows brownish glass in fresh specimens. On the hanging-wall side are amygdules filled with hornstone, chalcedony, quartz, chlorophæite, pyrite, and galenite.

(*c*) *Bergamaskite.* From Bergamo. Carries arfvedsonite.

(*d*) *Diorite-quartzifera-porfiroide* (Alfonso Cossa). From Cossato. Shows a grayish (*m*) crystalline groundmass with green and brown hornblende and quartz.

IV. QUARTZ-MICA-hornblende-porphyrite.

(*a*) *Paleophyre* (Gümbel). A dike in the Silurian of the Fichtelgebirge. A fine-grained reddish groundmass with well-crystallized phenocrysts of oligoclase, brown hornblende, brown biotite, and corroded quartz. Hornblende and biotite are strongly chloritized, and the groundmass is full of ferrite and calcite. It is an aggregate of (*m*) feldspar without any of the black bisilicates.

V. Diorite Glass

As the vitreous states of a rock are found to be more siliceous than the crystalline ones, the diorite glasses will be placed here. They are rare, but are found with all sorts of diorite eruptions, and are due to the rate of cooling rather than to the chemical composition. Following the analogy of other rocks, it may be permitted to say that the more acid diorites would be more ready to show glassy states on sudden cooling than the more basic, and to a greater extent.

1. Diorite-*mica-pitchstone-porphyry.* With conchoidal fracture; black; carrying phenocrysts of small rust-colored feldspars (mostly plagioclase), much mica in folia, few

grayish quartz grains. The base is light brown, dark-gray to black, and shows flow structure. Hornblende is scanty. Silica 62.02; Gr. 2.466. It is found in Italy and Scotland.

2. Diorite-*mica-hornblende-pitchstone-porphyry.* From the southern Tyrol, with mica and hornblende abundant (also enstatite), and with microfelsitic (*m*) base.

3. *Pitchstone-peperite* (v. Lasaulx). From Monte Trisa. A vesicular glass that changes to compact and granular states, with abundant (and often chloritized) hornblende, small feldspars (usually plagioclase), folia of mica, and pyroclasts of country-rock. It is amygdaloidal from a chalcedonic filling of vesicles.

(A full discussion of the various forms of occurrence, the states, textures, structures, minerals, as well as a definition of the porphyrites, will be found in its proper place under "Diorite," as these quartzose forms are infrequent, of small extent, and are but appendages to the large group of the diorites.)

GROUP 12. ANDESITE.

IIIb. HORNBLENDE-ANDESITE-DIORITE EXTRUSIVES.

(Necessary minerals: Ca-Na-feldspar and hornblende.)

ANDESITE (L. v. Buch).

A group of extrusives, generally dark-colored, with a restricted amount of glass base, but larger than in trachyte, and carrying a similar (*m*) web of minute crystals, plagioclase, hornblende, biotite, and pyroxene, either monoclinic (augite or diallage) or rhombic (enstatite or hypersthene), and with or without quartz. In this groundmass plagioclase and some, or all, of the above appear as phenocrysts.

These rocks were first studied in the Andes, whence the name, and in them was found a feldspar that was first called

albite, then oligoclase, and afterwards (from the locality) andesine. It is now known that all of the albite-anorthite series are present (except albite). In some varieties the prevalent minerals are andesine and labradorite, with oligoclase frequently, and rarely bytownite or anorthite. These carry, as a rule, hornblende and more or less black mica. In other varieties the feldspars belong to the andesine-anorthite end of the series, and carry the pyroxenes as necessary minerals. There is thus a more acid and a more basic division, which were called by J. Roth *hornblende-andesite* and *augite-andesite*. The latter is distinguished from basalt by its texture, and the much smaller amount of olivine. These were first classed with the trachytes, but were distinguished by the absence of alkali feldspars. There are certain rocks, however (to be described), which are transitions between these effusive groups, as they carry both feldspars. The group will be divided as follows:

I. Hornblende-andesite. Plagioclase and hornblende.

I*a*. Mica-andesite. Plagioclase and biotite (always some hornblende).

The andesites are effusive equivalents of abyssal diorite, and Judd reports that in the island of Mull there exist laccoliths that can be traced from diorite to andesite.

I. **HORNBLENDE-ANDESITE** (Roth), Gray Trachyte (v. Richthofen).

A (*m*) fine-grained to compact (sometimes coarse granular) groundmass of light or dark color (usually grayish or brownish black) and waxy, greasy luster, which (*m*) shows a moderate amount of glass base filled with a matt of minute feldspars, magnetite grains, hornblende, augite, and (sparingly) biotite, and carrying (*M*) phenocrysts of vitreous plagioclase, hornblende in large black prisms and needles, and some augite. As accessories appear (*M*) magnetite, apatite, quartz, tridymite, haüyne, garnet, and sometimes olivine, and (*m*) an abundance of cordierite, zircon, and (rarely) titanite.

Silica 55–62; Gr. 2.6–2.8.

It occurs in isolated peaks and dome-shaped masses (as in Germany, Scotland, etc.), in laccoliths; is common in lava-streams (as in the Andes), sometimes as surface sheets, rarely in dikes. It is found in the Siebengebirge, Eifel, Westerwald, Hebrides, central France, Hungary, Bosnia, the Canaries and Azores, East Indies, Japan, Australia, South and Central America, Nevada, California, Oregon. The (*M*) structure of quartzless hornblende- and mica-andesites varies greatly. The shades may be light or dark; as a rule, they are gray or brown, also bluish, reddish, red, bluish red, and reddish purple, and the reddening is due to the oxidation of the iron in the black bisilicates (usually augite). The groundmass is sometimes compact, as in augite-andesite, but usually rough and porous, as in trachyte; (*M*) fluidal structures are uncommon. In some localities the laminæ of mica are parallel. The phenocrysts are usually plagioclase, with either hornblende or mica, or both, and sometimes sanidine. When both feldspars are present, the variety is intermediate with trachyte. The plagioclase is generally in

regular crystals, sometimes tabular, and rarely irregular. It is usually andesine or labradorite, sometimes an oligoclase near andesine in composition (crystals sometimes over two inches in length), and sometimes one of the basic plagioclases, but rarely as basic as anorthite. Hornblende is in large black prisms and needles which are frequently several inches long; brown by transmitted light, but green when altered (to epidote, ferrite, or opal). In some cases the (*M*) phenocrysts disappear and hornblende is found only in the groundmass and (*M*). Biotite is in large hexagonal folia, brownish to blood-red by transmitted light. It rarely occurs in the groundmass, but exists as phenocrysts (*M*) and (*m*), and seldom without hornblende. Augite is abundant in the groundmass and as (*M*) phenocrysts (which are sometimes $\frac{3}{4}$ inch long) in both hornblende- and mica-andesites, and is rarely absent. Delessite is also reported from Italy. Rhombic pyroxene is found in such amounts as to form hypersthenic varieties. In such cases it is also found in the groundmass. Of the accessories, quartz appears in reddish grains, and an abundance of it changes the rock to *dacite*. Tridymite is sometimes 1.5 mm. long, but it generally is an uncertain component. Haüyne is in blue or white (from weathering) grains, and is essential in some varieties. Garnet is sometimes half an inch in diameter. Olivine is rare and sporadic; sometimes 4 mm., but usually (*m*). The secondary minerals are carbonates of lime and iron, bastite, quartz, opal, chalcedony, zeolites, and specular iron. Blackish-blue concretions are sometimes nearly an inch in diameter, and are composed (*m*) of plagioclase and some of the black bisilicates. We can distinguish:

1. *Granitoid Hornblende-andesite* (Müggge). A coarse-grained rock from S. Miguel, Azores, with neither groundmass nor glass base, but consisting of equally large grains (*M*) of plagioclase, hornblende, biotite, augite, and apatite.

A similar compound of plagioclase and hornblende with a small amount of glass and apatite, but no groundmass, is also reported.

2. *Augite-free Hornblende-andesite* (Hague). From the Eureka district, Nev., with (*m*) abundant glass inclusions, and needles of apatite.

3. *Hypersthene-hornblende-andesite.* At Lassen's Peak and Mount Shasta, Cal., San Salvador, the Siebengebirge, South America, and elsewhere. This is mostly hypersthene, with a little augite (*m*) in the groundmass, with phenocrysts of the same, plagioclase, hornblende, and mica.

I*a.* MICA-ANDESITE, Biotite-andesite.

A variety of the above where biotite is predominant over hornblende. In some cases the latter is almost absent from the groundmass. The rock resembles hornblende-andesite, and has similar essentials and accessories. The groundmass weathers to opal. Its usual colors are dark gray, red, reddish brown. It occurs in Greece, Asia Minor, South America, California.

Under this general subdivision come:

1. *Isenite* (Bertels). From the Sengelberg in the Westerwald, which was wrongly defined till Rosenbusch found a labradorite-bytownite-plagioclase, hornblende, much light-green augite (in the groundmass), irregular light-green grains of olivine, and sporadic biotite and apatite. It is named from a small stream (Eis, Latin *Isena*) in the neighborhood.

2. *Timazite* (Breithaupt), (in part) Trachytic Greenstone. From Timok valley in eastern Servia. A gray or greenish-gray felsitic groundmass carrying phenocrysts of white plagioclase, velvet-black hornblende (gamsigradite), mica, magnetite, and pyrite. Silica 51. A more acid variety belongs to dacite (*q. v.*).

3. *Trachydolerite* (Abich). A fine-grained compound of oligoclase or labradorite, hornblende, magnetite, augite, and sometimes mica, forming a gray or brown groundmass, and carrying the same as phenocrysts. Silica 54–61%; Gr. 2.7–2.8. This is an intermediate, as its name implies. It occurs compact, vesicular, etc., at the Peak of Teneriffe, in Kamtschatka, Italy, etc. This is an augitic hornblende-andesite, which frequently becomes augite-andesite by increase in augite and by entrance of olivine, as at Löwenberg, Siebengebirge · shades into dolerite. It is no longer known as a separate rock.

Hornblende-andesite Glass.

This is reported as yet only in a few cases. Zirkel states that it is not found in Hungary nor the Siebengebirge, where there occurs the greatest development of the rock.

(*a*) *Perlitic* Hornblende-andesite. In a (*m*) crystalline groundmass occur perlitic spheres of glass. From Akerotivi, island of Thera. At Balos the spheres can be separated from the matrix when it is fractured.

(*b*) *Perlitic* Hornblende-andesite-pitchstone. A black pitchstone with great spherules, from Muzukishima, Japan, with almost (*m*) biotite and garnet, and great (*M*) plagioclases as phenocrysts.

(*c*) *Perlitic* Hornblende-andesite-*pumice*. At the last locality, and the Isle of Luzon. The pumice is a white glass with dark-green hornblende, glassy andesine, and biotite, among which are distributed the glassy spherules.

(*d*) Hornblende-andesite-*pumice*. At Montserrat, San Salvador, and Peru. The pumice is rose-red, and frequently has the vesicles so much stretched as to resemble fine fibers in a glassy mass that carries phenocrysts of the component minerals.

GROUP 13. DIORITE.

IIIb. HORNBLENDE-DIORITE-ANDESITE INTRUSIVES.

(Necessary minerals: Ca-Na-feldspar and hornblende.)

DIORITE (Haüy).

A holocrystalline, usually coarse- to fine-grained compound of a Ca-Na-feldspar and hornblende, with mica and pyroxene. This also shows compact and vitreous states and exhibits phenocrysts.

Silica 45–67; Gr. 2.6–2.9.

It occurs rarely in small bosses, but mostly as dikes and intrusive sheets; the former are usually fine-grained at their margins and coarsely crystalline-granular towards their middle. The intrusive sheets are sometimes of considerable extent, and follow more or less closely the planes of stratification of the rocks, usually crystalline schists, gneiss, etc., into which they have been intruded. Dikes of diorite are occasionally to be seen breaking through granite. Diorites are generally more or less irregularly jointed, but in some instances a rude columnar structure is developed. Sometimes the diorites show a concentric spheroidal structure when weathered. The selvages of dikes abound in schistoid structures parallel to the dike-walls, and there is sometimes a quite sharp line of demarkation between the massive-granular and the schistoid parts. Passages between quartz-diorites, mica-diorites, etc., may occasionally be seen, and the different varieties appear to be mere local differentiations of the same rock. Diorite is also reported as passing (in the same mass) into picrite, and at Cortlandt, N. Y., it passes, in a dike, into hornblendite. It is found in Sweden, Finland, the Urals, Austria, Saxony, Bohemia, the Thuringian Forest, Odenwald, Schwarzwald, Vosges, Hungary, Switzerland, Italy, Corsica,

France, Spain, Great Britain, Greenland, Asia, South Africa, Canada, and in the United States at Cortlandt, Ft. Montgomery, and in Orange County, N, Y.; Deckertown, N. J.; Kennebunkport, Me.; Livermore Falls and Dixville Notch, N. H.; the valley of Lake Champlain, Nevada, California, Yosemite Park, Michigan, Minnesota, and Alaska. The principal mass is coarse- to medium- and uniform fine-grained; microcrystalline with faint glimmer, and colored dark green to black, and compact, black, and basaltic. The medium fine-grained state has been called "microdiorite" in some cases, as analogous to "microgranite," "microsyenite." These are not separate rocks, but states peculiar to the manner of cooling. In the following varieties hornblende is never absent, and the other black bisilicates never predominate:

I. *Hornblende*-diorite, or typical *diorite.*
II. *Mica*-diorite.
III. *Diorite-porphyrites.*
IV. *Diorite-aphanite.*

I. DIORITE (Haüy).

A usually granitoid compound of oligoclase (sometimes andesine, labradorite, or anorthite) and hornblende, with mica, pyroxene, and quartz, occasionally orthoclase, usually apatite, and ordinary and titaniferous magnetite.

Silica 45–63; Gr. 2.6–2.95.

This varies in texture according as the rock is in large or small masses. In bosses it is coarse-grained in the center, in dikes usually uniformly fine-grained (like aplite), and in small dikes or on the selvages of some large ones and of bosses it is compact. The color is usually greenish, and on this account the rock was formerly classed (with diabase and gabbro) as a "greenstone." The absolutely

compact states in small dikes are black and basaltic. It is frequently porphyritic, globuliferous, and sometimes drusy, rarely amygdaloidal, and by squeezing is altered frequently to hornblende-schist. Plagioclase is usually oligoclase, anorthite causes a distinct variety, and andesine and labradorite are sometimes predominant. The color is usually white with yellowish or greenish shades—occasionally reddish. The luster is as frequently dull as strong, and when fresh they lack the glassy habit of andesine in the andesites, though they may be transparent. They are not so perfectly crystallized as are the orthoclases, and usually occur in regular and tabular forms with abundant twinnings; but the angles are more rounded and the granular habit more prominent. Hornblende is the ordinary black mineral with shades of green; in stout prisms or grains, sometimes in lath shapes, acicular, and in irregular patches; strong luster on cleavages. By transmitted light it shows greenish shades, and thus differs from the brown basaltic form, which occasionally occurs—especially in the porphyritic and basic varieties. The brown color is generally associated with the stout crystals, and the green with the lath and acicular shapes. It alters to viridite, serpentine, chlorite, and epidote, which accounts for the greenish color of the rock, and allows us to suppose that the original color was black or gray. The only essential in this variety is mica, but it occurs more prominently in the quartz-diorites (as would be supposed). It is biotite. The other minerals are only accessory. Quartz, when prominent, forms quartz-diorite. It is then, as already stated, in (*M*) rounded or angular crystalline grains, but in the porphyritic states shows sometimes double pyramids, and is generally more idiomorphic. Pyroxene cannot be depended upon. In many localities it is wanting, and when abundant forms pyroxene-diorite; when highly predominant, diabase.

As the basic component it is usually idiomorphic. It is found (*m*) in the groundmass of some diorite-porphyrites. Orthoclase frequently occurs (*m*), but more especially in the quartzose varieties, and forms micropegmatite with quartz. Apatite, magnetite, olivine, and orthite are usually present and (*m*); titanite, garnet, and tourmaline are (*M*), and the last two especially in the quartzose mica varieties. Diorite differs from syenite in having plagioclase for orthoclase; in its greenish (rather than red) color; its prominent hornblende on a weathered surface (by loss of feldspar); by the fusibility of the feldspar, and the greater specific gravity. It differs from the granulitic gabbros by having hornblende instead of pyroxene; by its lower density; and by its less strong effervescence with acids when fine-grained or compact, owing to the greater proportion of secondary calcite in the gabbros. Some authorities place the coarse-grained, fine-grained, porphyritic, and similar states of diorite in separate divisions; but these are found more or less with all occurrences, and can be readily noted in the field, as they have the same mineral composition. The following varieties have been noted:

1. **Leuciite** is only a fine-grained dike-form from the Melibocus.

2. **Scapolite**-diorite. An altered gabbro from southern Norway, where plagioclase is almost entirely altered to scapolite, and pyroxene uralitized. It is also found along the Ottawa River in Canada.

3. **Anorthite**-diorite, Corsite (Zirkel). A diorite composed of anorthite and some oligoclase, blackish-green hornblende and some quartz. Silica 48; Gr. 2.76. Named by Zirkel from its abundance in Corsica.

(*a*) *Orbicular* Diorite, Napoleonite. A variety of the above where the components form alternating concentric layers about kernels. The kernels consist either of anorthite

or hornblende, or both, and they likewise show a radial structure. The balls are from one to three inches in size, and a section shows alternating rings of light and dark color. It is found near Ajaccio, Corsica. This is accepted as a peculiar arrangement, but not as a new compound, and thus has no claims to be a separate species.

4. **Labradiorite.** A diorite where labradorite replaces oligoclase. Silica 47–50; Gr. 2.7–2.9. This has no claims to be classed as a separate rock, as Tschermak's theory of plagioclase allows all variations between oligoclase and labradorite to occur in diorite.

5. *Hemithrène* (Brongniart), Kalkdiorit (Senft). A name given by Brongniart to rocks composed of hornblende and calcite, part of which are now found to be diorites. In any case the calcite is an alteration product. Senft's rock is a dark-green compound of oligoclase, hornblende, and mica with calc-spar. The French rock is from the Auvergne; the German variety from the Thuringian Forest.

II. **MICA-DIORITE** (Delesse), Biotite-diorite.

A uniformly granular compound of oligoclase or andesine, orthoclase, biotite in irregular folia, brown and green hornblende, pyroxene (augite or hypersthene), and quartz in rounded or angular grains. Generally of a dark color and almost black.

Silica 47–59; Gr. 2.65–2.89.

It occurs in bosses and dikes in crystalline schists and older sediments; rarely in surface extrusives. It is found in the Tyrol, Frankenwald, France, Norway, Mexico, California, the Pah-Ute range, Cortlandt, N. Y., etc. V. Cotta objects to calling this a diorite on account of its orthoclase. It is a transition to quartz-mica-diorite, and that to granite, as already stated (p. 187). The plagioclase is sometimes altered; the hornblende more often brown than green, and

altered to chlorite and epidote. Augite, when present, is altered to chlorite, calcite, and ores, rarely uralitized. Hypersthene is sometimes altered to bastite. Garnet is accessory. Its fine-grained form is like kersantite without calcite.

III. DIORITE-PORPHYRITES.

As stated on p. 178, a *porphyrite* is a rock with a compact matrix of *plagioclase* and exhibiting phenocrysts. It differs from a *porphyry*, which is a compact rock of orthoclase or orthoclase-quartz mixture. The porphyrites can be divided according to their content of the black bisilicates. The mica-porphyrites have already been described, and the mixture with pyroxene forms the gabbro-porphyrites. Those with hornblende will follow here as diorite-porphyrites. These can be divided into:

1. Diorite-*porphyrite*.
2. *Mica*-diorite-porphyrite.
3. Diorite-*aphanite*.

1. DIORITE-PORPHYRITE, Hornblende-porphyrite.

In a groundmass (described on pp. 180, 202,) are phenocrysts of hornblende, also plagioclase and mica. The groundmass weathers lighter.

Silica 39–65; Gr. 2.6–2.7.

It occurs in sheets and dikes in Asia, Africa, central and eastern Europe, Scotland, the New England States, and Nevada. Its states resemble those of the porphyrites and mica-porphyrites, and with the above occurrences are vesicular states, tuffs, etc. The vesicles are sometimes empty and sometimes filled with green earth, calcite; and in some localities the amygdules form the greater part of the mass. The rock is usually irregularly jointed and fissured; rarely columnar or tabular. It is not so abundant as the more acid

porphyrites. Plagioclase phenocrysts are white, yellowish, or reddish, and usually dull. Hornblende is in irregular stout prisms or acicular shapes, and brownish black. Biotite is in hexagonal tables, seldom in folia. Quartz is rare.

(The first three types following are entirely dependent on (*m*) characteristics.)

(*a*) *Suldenite*, Andesitic Porphyrite (Stache and v. John). From the Suldenfern in the Ortler Alps, with 54–62 silica. The groundmass is light to dark gray, with (*m*) phenocrysts of black hornblende (prisms); (*m*) plagioclase and orthoclase in small amount, with accessory augite, biotite, and quartz.

(*b*) *Ortlerite*, Greenstone-porphyrite (Stache and v. John). From the Ortler Alps, with silica 48–54. Blackish-green to grayish-green groundmass, fresh glassy black prisms of hornblende (4–6 mm.), and sometimes in bundles. Part of Gümbel's *nadeldiorit*, from eastern Bavaria, is placed here by Zirkel.

(*c*) *Propylitic* Porphyrite (Stache and v. John). From the Ortler Alps, with silica 52–57. Blackish-green to grayish-black groundmass of monotonous appearance, carrying phenocrysts of plagioclase (with orthoclase) in abundance, always hornblende (mostly mixed with chlorite, epidote, and calcite); biotite is only accessory.

(*d*) *Porfido-rosso-antico.* From the west coast of the Red Sea, in a dike in granite. This is the famous red porphyry of history. In a blood-red (*M*) compact groundmass are abundant small snow-white or rose-red striated plagioclase phenocrysts and lustrous black acicular hornblendes, with usually small scales of specular hematite. Quartz occurs in irregular veins, never in regular primary grains. Silica 64.

2. **MICA**-diorite-porphyrite.

In a typical porphyrite groundmass are phenocrysts of oligoclase and orthoclase, with hornblende and mica in equal proportions.

Silica 61 ; Gr. 2.6–2.7

This occurs as a transition between the hornblende- and mica-porphyrites, and is found with porphyrites of both species. It is especially found in the Saar-Nahe district, the central Alps, in China, and elsewhere.

3. DIORITE-APHANITE.

A greenish-gray to black (*m*), holocrystalline to compact groundmass similar to those noted on pp. 180, 200, and carrying few or no phenocrysts.

The term aphanite was applied to a mass so compact that its constituents could not be resolved with a lens, and whose color was green to black. It was the compact state of the "greenstones," diorite, diabase, and gabbro. The same term is still employed to denote the compact state, which bears to the granular states the relation that basalt does to dolerite.

The silica and specific gravity are as in the diorite-porphyrites, and this may be said to be their clear groundmass. It is recognized mainly by its actual association with diorite. Its bulk analysis will vary so that it may approach and equal that of many diabase-aphanites, but its specific gravity is generally lower. It carries a much lower amount of calcite than does diabase-aphanite, and will not effervesce so strongly. It occurs at Bischofswerda, Saxony, and elsewhere, in narrow dikes and apophyses from dioritic dikes and bosses.

GROUP 14. PYROXENE-ANDESITE.

IIIc. PYROXENE-ANDESITE-DIORITE EXTRUSIVES.

(Necessary minerals: Plagioclase, hornblende, and a pyroxene.)

PYROXENE-ANDESITE.

An andesite containing abundant pyroxene.

Silica 50–68; Gr. 2.72–2.8.

Pyroxene-andesite is the mineralogical equivalent of basalt. It is more than that, as it is seen passing into basalt at Löwenberg in the Siebengebirge, where the so-called "trachydolerite" shades into augite-andesite, and this by the acquisition of a somewhat higher olivine content becomes basalt. At Arran, Scotland, augite-andesite passes into tholeite (with intersertal texture), and that by still further crystallization of the groundmass into diabase. Augite-andesite is therefore a transition between hornblende-andesite and the gabbros. As an appendix to this group will be placed the so-called "propylite" and "quartz-propylite." The majority of authorities recognize these only as peculiarly metachemized states of a number of different rocks; but the name, as Rosenbusch suggests, is valuable as distinguishing those alterations. Pyroxene-andesite can be divided into:

I. *PYROXENE*-andesite (Zirkel). Plagioclase and one of the pyroxenes.

(*a*) *Augite*-andesite (Roth). Plagioclase and augite.

(*b*) *Diallage*-andesite (v. Drasche). Plagioclase and diallage.

(*c*) *Hypersthene*-andesite. Plagioclase and hypersthene.

(*d*) *Enstatite*-andesite (Kotō). Plagioclase and enstatite.

(*e*) *Olivine-pyroxene*-andesite.

II. *PYROXENE*-andesite glass.

III*a*. *PROPYLITE*, a metachemized state of diabase, diorite, or any of the andesites, due to solfataric action.

b. *Quartz*-propylite, a similar state of any of the quartzose varieties of the above, and of quartz-porphyry of the Washoe type.

I. AUGITE-ANDESITE (Roth).

A dark-colored groundmass varying from glassy to trachytic, composed of (*m*) plagioclase, augite (monoclinic, rhombic, or, infrequently, triclinic), carrying (*M*) phenocrysts of plagioclase, hypersthene (and rarely augite), scanty hornblende, tridymite, quartz seldom, biotite, and olivine.

Silica 56–68 (average 60); Gr. 2.72–2.74.

It occurs in lava sheets and streams, and in dikes, widely spread among the active volcanoes of Europe and Asia, Azores, South and Central America, and in the Great Basin of the United States. The famous eruption of Krakatoa extruded great amounts of this rock, so that the floating pumice hindered navigation in the Sunda Straits for several days, and the ashes were scattered so widely and profusely that thirty tons were shoveled from the deck of an American ship sixty miles distant. Zirkel notes four types of the rock:

(1) Semivitreous; luster waxy, pitchy; color more nearly deep brown than greenish black; sometimes compact, sometimes fine-porous; groundmass carrying a few phenocrysts of whitish or yellowish feldspar. This is the type in North and South America, Hungary, Java.

(2) Less characteristic and widely distributed; is like hornblende-andesite, or the light basalts, as in Japan. A gray or dark-brown groundmass, somewhat porous and "coarse porphyritic," with (*M*) phenocrysts.

(3) A more extended type (trachytic): light grayish red;

rough; somewhat porous; carrying the ingredients in the pores as crystals. In Hungary, Mexico, Italy.

(4) A light-weight, gray, and porous groundmass, carrying specular iron, and biotite in the pores, as in the lava of Auvergne (Little Puy de Dôme).

The plagioclases are stout tabular, and twin in the Carlsbad and Baveno types. They are andesine to anorthite, mostly fresh, but weather to opaline masses and epidote. Sanidine also appears in small amounts. Augite is abundant (*m*), but infrequent (*M*), and yellowish to greenish brown by transmitted light; usually fresh in the rocks with glass base. Rhombic pyroxene is usually hypersthene in slender needles, sometimes enstatite and bronzite, sometimes the triclinic variety, sometimes diallage. Hornblende is not so frequent or abundant as in the other variety of andesite, and generally occurs only in a few large prisms. Biotite is infrequent; quartz in a few cases (*M*) and 2 mm., generally (*m*); tridymite more frequent than quartz in both pores and groundmass; olivine infrequent (mainly occurring when augite increases and rhombic pyroxene diminishes).

Judd describes the weathering of augite-andesite as having four phases: (1) the conversion of augite to viridite; (2) the formation of opacite; (3) the hydroxidation of opacite to red or brown ferrite, to form the tints that color all porphyrites; (4) the kaolinization of feldspar, and formation of calcite and chalcedony. The result is a tuff. Emmons states that tridymite is found in the cavities and clefts of the partly weathered rock, and more rarely opal. When weathering advances, the reddening of the groundmass takes place, and the fluxion structure—not seen in the fresh rock—appears. The feldspar remains fresh while the red color fades to pink, and this to yellowish gray, and then kaolinizes, while the black bisilicates bleach and disintegrate.

The rock in some localities shows a white crust on weathering, while the interior is dark.

1. *Quartz*-augite-andesite (Tschermak), when the quartz is in phenocrysts and also in the groundmass. Silica 63–65; Gr. 2.61. Found in South America, New Zealand, Japan.

2. *Mijakite* (Petersen). From the island of Mijakeshima, Japan. An andesite where the pyroxenic mineral is (*m*) in short pellucid columns, and is triclinic, like babingtonite. An American triclinic pyroxene-andesite is also reported.

I*b*. **Diallage**-andesite. From the Smrkouz Mountains, Steiermark. A dark-brown, fine-grained rock with numerous phenocrysts of plagioclase and darker foliated crystals of diallage. A similar rock occurs in Bohemia. Some authorities place *ophite* here.

I*c*. **Enstatite**-andesite. With enstatite more or less abundant and monoclinic pyroxene; generally weathered. Bronzite is reported in one variety from Japan. Occurs there and in South America and New Zealand.

I*d*. **Hypersthene**-andesite. This mineral is found in many andesites in slender (*m*) prisms, frequently altered—sometimes to bastite, and sometimes to fibrous hornblende. It is frequently (*M*) in great individuals. The rock occurs in Japan, the Caucasus, Mexico, Colombia, and the Great Basin of the western United States.

I*e*. **Olivine-pyroxene**-andesite. It is a dark-colored (*M*) fine-grained rock, with holocrystalline groundmass of plagioclase, pyroxene, and magnetite, with phenocrysts of plagioclase and olivine. Here part of the so-called "trachydolerite" with olivine would be placed. This rock is transitional to basalt. Found in South America, etc

(NOTE. Some authorities place *tholeite* here.)

II. Pyroxene-andesite Glass.

There are abundant cases of vitreous states to this group in connection with the widespread lavas of the same.

AUGITE-ANDESITE.

1. *Pitchstone.* From the Caucasus, Scotland.

(*a*) *Felsite.* From Eskdale, Scotland. A devitrified pitchstone.

2. *Perlite.* From Japan.

3. *Obsidian.* From Armenia, island of Melos, Ardnamurchan, Scotland, island of Hokkaido, Japan. Silica 53–59. Color brownish to greenish black.

4. Obsidian-*porphyry.* From Mount Ararat, with silica 77; carrying numerous phenocrysts of plagioclase and dirty green biotite; found in connection with a rock of this class. From Hokkaido, Japan, is a black glass, transparent on thin edges, with silica 74, and many phenocrysts.

5. *Pumice.* In many flows as a more or less thick crust, and in large masses (as from Krakatoa). It has the vesicles filiform and carries a small number of phenocrysts. Immense masses of this state of the rock blocked the Straits of Sunda after the eruption of Krakatoa. Color straw-yellow light yellowish gray. Silica 61–71.

BRONZITE-ANDESITE.

Here come two varieties of this rock with and without olivine:

1. *Boninite*, Bronzite-limburgite (Petersen and Kikuchi). A glassy state with no feldspar from the Peel Island group, near Japan; carrying olivine and diallage-like augite.

2. *Sanukite* (Weinschenk). A dense gray or black rock, with conchoidal fracture and (*m*) abundance of magnetite, acicular crystals of bronzite, and monoclinic augite, forming a colorless glass with infrequent large phenocrysts of pla-

gioclase and garnet. From Sanuki, Japan, and elsewhere in that country. This bears to andesite the relation that augitite does to basalt.

III*a*. **PROPYLITE** (v. Richthofen), Greenstone Trachyte (in part).

III*b*. **QUARTZ**-propylite (same authority).

A fine-crystalline rock with devitrified base, consisting of a feldspar from which calcite has been removed, and a light-green mineral, mostly epidote, which is the secondary (or even later) derivative from one of the black bisilicates. Always soft from weathering.

Silica 57–72; Gr. 2.7–2.9.

These are no longer classed as separate rocks by all authorities. Zirkel still holds to their being distinct varieties. Propylite is the country-rock of the Comstock lode, and is derived, as first claimed by Wadsworth and later shown by Becker, from the weathering of a number of rocks into which it can be traced. The black bisilicates of these rocks (hornblende, augite, and mica) uniformly pass into a chloritic mineral which, in its turn, becomes epidote of a vivid yellow tinged with green. The weathering of andesite, augite-andesite, diorite, and diabase produce what is known as propylite; while the same process in their quartzose varieties, and in some quartz-porphyries, forms what has been called quartz-propylite. It also occurs in the Western Isles of Scotland, the Siebengebirge, and Hungary. Szabo was the first to object to the rock on the ground that it was a solfataric product. In 1882 Becker reported that the Washoe rock was altered as above stated. The arguments of Zirkel against the rejection of the name for a distinct rock seem to fail, as the want of an andesitic

glass base in propylite may be due to the fact that the original rocks had none, as in other cases; or to its loss by devitrification; or, again, in the general wreck of the rock, as Emmons reports the complete kaolinization of an augite-andesite in the island of Capraja. The other argument, that propylite is not found as a decomposition product in many andesite regions, may be answered by the fact that solfataric action, which produces propylite, is not common; but in this case propylite is directly traced into rocks of varying name. Rosenbusch remarks that the name may be useful to denote a peculiar kind of alteration of the above rocks. As such it is used here.

GROUP 15. PYROXENE-DIORITE.

IIIc. PYROXENE-ANDESITE-DIORITE INTRUSIVES.

(Necessary minerals: Plagioclase, hornblende, and a pyroxene.)

PYROXENE-diorite.

A transition between diorite and the granulitic gabbros, as pyroxene-andesite is between andesite and basalt. The rock is more basic than diorite; hornblende is very subordinate, and the plagioclases more basic than oligoclase. Olivine becomes more prominent, and mica, quartz, and orthoclase are rare. The monoclinic pyroxene is usually augite, and this mineral is more frequent than any pyroxene. Diallage is rare. The augite is green (sometimes brown) and idiomorphic (also in grains). Rhombic pyroxene is hypersthene or bronzite, which now and then occur, and are more or less altered to bastite. Occasionally quartz is found quite abundant. The texture varies between the holocrystalline one of diorite and the ophitic one of diabase. Its lower specific gravity tells it from diabase, as well as its association with dioritic rocks.

I. **AUGITE**-diorite (Zirkel).

A diorite with predominant augite (diallage or malacolite), green (and generally brown) hornblende, labradorite, some olivine and titanite.

Silica 47–57; Gr. 2.7–2.98.

It is found in Great Britain and the Channel Islands, Argentine Confederation, Bohemia, Norway, Odenwald, Hungary, the Alps, Sumatra, the Andes, Minnesota, and elsewhere. Of the accessories, titanite is (*M*), olivine rarely (*M*), magnetite and apatite (*m*).

1. *Brown Diorite*, when hornblende is brown and basaltic. This variety is usually associated with pyroxene rocks, and tends to pass into gabbro by increase in pyroxene, and into pyroxenite by failure of feldspar and hornblende. It is associated with norite and passes into it, and also into massive brown hornblendtite at Cortlandt, N. Y. It also occurs in a few localities in Europe, and at Montreal, Canada. This color is common in porphyritic diorites, camptonites, etc. As accessories are apatite, magnetite, and hypersthene.

II. **QUARTZ**-augite-diorite.

A variety of the above carrying more biotite and quartz, and less olivine. The silica content is higher also. Sometimes scapolite occurs. It occurs in Brazil, the West Indies, the Andes, etc.

III. **HYPERSTHENE**-diorite.

A coarse- to medium-grained compound of plagioclase (sometimes epidotized), brown hornblende, and hypersthene. The latter also forms concretions. In Portugal, West Indies.

IV. **GABBRO**-diorite (Törnebohm).

An alteration product of gabbro and norite where the pyroxene has uralitized. In Scandinavia.

V. **CAMPTONITE** (Rosenbusch).

(*M*) a rock rarely coarse-grained, but usually dense hypidiomorphic granular compound of plagioclase, hornblende, pyroxene, mica, with occasional olivine, and carrying phenocrysts of lustrous (*M*) rod-shaped basaltic hornblende, andesine, magnetite, and weathering to a rusty brown.

Silica 39–54; Gr. 2.7–2.9.

This rock is found in dike and surface effusions, and is intermediate between the diorites and diorite-porphyrites, and between the diorite-porphyrites and the melaphyres. It was placed by Rosenbusch with his lamprophyres; but M.-Levy and Zirkel have relegated it back to diorite on the ground of the impropriety of separating dike-forms. It generally has a low augite content, but sometimes has a very high one. Rarely it is amygdaloidal. It is placed with the augite-diorites on account of its having basaltic hornblende entirely, and thus coming under the same head as "brown diorite" above. It was first noted by Hawes at Campton, N. H., and has been since noted in the Champlain valley of Vermont, in New York, Maine, Montreal, Canada, Sierra Nevada range of California, U. S. Colombia, Tyrol, south Norway, etc.

1. *Augite*-camptonite. From near Christiania, Norway, and near Lewiston, Me. With abundant augite and much olivine, so that, as Kemp reports, it forms a transition to the melaphyres.

VI. HORNBLENDITE (Dana).

A coarse to fine granitoid (sometimes compact) blackish aggregate of compact brown hornblende, which is usually a paramorph of one of the pyroxenes.

Silica 46–49; Gr. 3–3.1.

A dike-rock of rare occurrence, and not to be confounded with the metamorphic massive rock called amphibolite. It is sometimes a segregation in part of the dike, and generally the altered form of a pyroxenite, as above stated. It occurs in the Cortlandt (N. Y.) diorite series, Amador and Calaveras counties, Cal., the Argentine Confederation. *Mica*-hornblendite is found in Nova Scotia.

BASIC DIVISION—PYROXENE ROCKS.

These are divided, according to their alkali and Ca-Na content, as follows:

I. ALKALI SECTION:

(*a*) Groups 16 and 17. *Feldspathoids*, alkali feldspar, magnetite, olivine, plagioclase, amphibole, mica, quartz.

Extrusives, Nephelinite, Leucitite; *Intrusive*, Iolite.

(*b*) Group 18. *Feldspathoids*, *olivine*, magnetite, alkali feldspar, plagioclase, amphibole, mica, quartz.

Extrusives, Nepheline, Leucite, and Melilite Basalts; *Intrusive*, none.

II. ALKALI-LIME-SODA SECTION:

(*a*) Groups 19 and 20. *Feldspathoids*, *plagioclase*, magnetite, olivine, amphibole, mica, alkali feldspar, quartz.

Extrusives, the Tephrites; *Intrusive*, Theralite.

(*b*) Group 19 (*con.*). *Feldspathoids*, *plagioclase*, *olivine*, magnetite, amphibole, mica, alkali feldspar, quartz.

Extrusives, the Basanites.

III. LIME-SODA SECTION:

Groups 21 and 22. *Plagioclase*, *magnetite*, *olivine*, amphibole, mica, feldspathoids, alkali feldspar, quartz.

Extrusive, Basalt; *Intrusive*, Gabbro.

GROUP 16. NEPHELINITE-LEUCITITE.

Ia. NEPHELINITE (LEUCITITE)-HOLITE EXTRUSIVES.

(Necessary minerals: Feldspathoids and pyroxene.)

In this group there is no plagioclase nor olivine. We distinguish:

1. *Nephelinite*, where the feldspathoid is nepheline.
2. *Leucitite*, where it is leucite.

1. NEPHELINITE (Rosenbusch).

A coarse-granular to compact (usually porous) principal mass, usually bluish to dark green, or greenish, grayish, or pitch black, less frequently grayish white, rarely light wine-yellow; subgreasy or pitchy luster; composed of nepheline and augite, with magnetite, apatite, leucite, haüyne, and melilite.

Silica 41–47; Gr. 2.9.

This occurs as slaggy lava-streams and in dikes and plugs, in the Erzgebirge, near the lake of Laach, in Bohemia, Sweden, Cape Verdes, South Africa. The states are:

(*a*) *Doleritic* Nephelinite. A coarse-grained compound of nepheline, reddish-brown augite and magnetite, with sometimes sanidine, with the interstices filled with a mixture of them, and no glass base. This state is difficult to distinguish from nepheline-dolerite, as the olivine in the latter is seldom readily recognized (*M*), and it is only by tracing it into the basaltic state that a distinction can be made. A small proportion of olivine would make this a nepheline-dolerite.

(*b*) *Fine-grained* to *Compact* (Basaltic) Nephelinite. In a groundmass colored as above, and rarely without phenocrysts, are (*M*) haüyne, green and brown augite, black mica, apatite, magnetite, and, rarely, melanite; and (*m*), in addition, nepheline, melilite, leucite, and more or less glass base.

As accessories, hornblende is rare, sanidine and olivine sporadic. The haüyne is often half an inch in size and is the predominant accessory, the others being quite subordinate. In the Erzgebirge and Bohemia.

(*c*) *Camptonitic* Nephelinite (Rosenbusch). A (*m*) groundmass rich in haüyne and poor in nepheline, with augite, hornblende, and melilite, carrying large phenocrysts of biotite and melanite. It also carries a little sanidine, and is found in the region about the Kaiserstuhl.

2. **LEUCITITE,** Sperone (Italian local name).

In a usually microcrystalline to compact groundmass of shades of gray (from very light to black), and usually porous, are phenocrysts of (*M*) leucite, augite, titanite, and magnetite that are rarely so abundant or so large as to make the rock appear doleritic. As accessories are nepheline, haüyne, biotite; sometimes melilite and garnet.

Silica 40–50; Gr. 2.5–2.81.

This occurs in lava-streams in the Eifel, Erzgebirge, Bohemia, abundantly in Italy, Cape Verdes, Algiers, and in the Leucite Hills of Wyoming. The amount of leucite and its habit vary in these rocks. When it is prominent, augite, magnetite, and titanite are less so; in other rocks all are equally prominent. Leucite varies from a well-crystalline to a rounded form, and when the latter it is accompanied by brown augite and forms *basaltoid* leucitite; when well crystallized, the augite is green and they form *tephritoid* leucitite (both states are (*m*)).

(*a*) *Lava Sperone* (local name). From the Alban Hills and elsewhere in Italy. A light, porous, brownish or yellowish gray rock composed of small grains of leucite and much smaller crystals of yellowish brown garnet, with augite, haüyne, biotite, and sometimes magnetite and specular

hematite; in a groundmass of leucite and augite, with some glass base, magnetite and sporadic plagioclase.

(*b*) *Haüynophyre* (Rammelsberg). From the volcano Vultur, near Melfi, in S. Italy. A rough, porous, dark-gray to black, generally fine-grained groundmass, composed of abundant (*m*) leucite, much nepheline, augite, melilite, magnetite, apatite, scanty sanidine, some olivine, and black magnesia-mica; carrying phenocrysts of haüyne, augite in abundance, and some olivine, mica, and leucite. Silica 40–50; Gr. 2.5–2.8. The haüyne is abundant, and 2–10 mm.; blackish-gray conchoidal fracture and scaly structure; cleavable when sky-blue; sometimes red from secondary growths of sesquioxide of iron; sometimes colorless and cleavable. This is a transition between nephelinite, leucitite, and a similar haüyne rock, as it contains an abundance of each. Zirkel puts it here, Rosenbusch under nephelinite, and Deecke under Rosenbusch's "nepheline-leucite-tephrite," as a haüyne-melilite variety. If the feldspar be sanidine, as reported by Mann, it would fall, not under tephrite, but under phonolite. This is a good example of the small variation in mineral content that is necessary to move a rock from one species to another, and this is a good example of the meeting of the black bisilicates, feldspars and feldspathoids in one rock. It is a transition between phonolite, trachyte, rhyolite on the one hand, and basalt, pyroxenite, and the peridotites, on the other.

(*c*) *Mica*-leucitite. From Leucite Hills, Wyo. A light yellowish gray, very fine-porous, felsitic rock, showing only stripings of bronzy, brownish yellow, and brownish red mica. (*m*) it appears as a crystalline-granular compound of predominant leucite and some augite, with a small amount of magnetite, apatite, and nepheline. Silica 56.30.

GROUP 17. IOLITE.

Ia. NEPHELINITE-IIOLITE INTRUSIVES.

(Necessary minerals: Pyroxene and feldspathoids.)

IIOLITE (Ramsay and Berghell).

A coarse- to micro-crystalline compound of elæolite and augite with garnet (iiwarrite).

Silica 42.79; Gr. 2.9.

An elæolite-augite rock free from feldspar and olivine, and considered as the intrusive equivalent of nephelinite. It occurs in dikes and narrow apophyses in the Iiwarre Mountains in northern Finland, where it was thought to be an elæolite-syenite, but was found to be without feldspar. The elæolite is fresh, grayish white to light gray, and in small allotriomorphic grains with greasy-vitreous luster. Augite is idiomorphic (prisms and tables); apatite is abundant. The garnet is a titaniferous lime-iron variety, and titaniferous melanite is common, and also light-red titanite. Elæolite alters to cancrinite and calcite. In the mass apatite and elæolite are equally predominant. Thirty-seven per cent of the rock powder is soluble in acids.

GROUP 18. NEPHELINE-, ETC., BASALTS.

Ib. FELDSPATHOID BASALTS.

(Necessary minerals: Pyroxene, feldspathoids, and olivine.)

These are divided, according to the feldspathoid, into:

1. Pyroxene, olivine, and nepheline, *Nepheline*-basalt.
2. Pyroxene, olivine, and leucite, *Leucite*-basalt.
3. Pyroxene, olivine, and melilite, *Melilite*-basalt.

1. **NEPHELINE**-basalt, Anamesite, and Dolerite.

A coarse- to micro-crystalline (and compact) compound of nepheline, augite, and olivine (usually of dark color) which in the *dolerites* shows the ingredients plainly, but in the *basalts* usually shows (*M*) olivine alone, sometimes augite. As (*M*) accessories are sporadic hornblende and mica. Plagioclase is generally absent.

Silica 38–45 ; Gr. 2.89–3.22.

This occurs as widely spread in the old world (especially in Germany) as the feldspar-basalts, and is found as surface and intrusive sheets, lava-streams, plugs and dikes. In the United States it is rare, and the basalt state is reported from Austin, Tex., Kawsoh Mountains, Nev. and Elk Mountains, Col. The term *dolerite* refers to the coarse-crystalline state, *anamesite* to the medium- to fine-crystalline state, and *basalt* to the microcrystalline to compact (see later under "Feldspar-basalt"). Nepheline is usually well crystallized and apparent in *dolerite*, but only (*m*) in *basalt.* In some cases nepheline forms a granular and sometimes an irregular interstitial amorphous filling in which the other minerals appear, as in phonolite, and it readily alters to zeolites. The other minerals appear as in basalt (p. 227). The principal accessories are leucite, haüyne, and melilite. These sometimes preponderate to form their own types of basalt. Plagioclase can enter in a slight amount without placing the rock among the *basanites ;* a withdrawal of both feldspar and feldspathoids makes it a *limburgite*, and a loss of olivine forms *nephelinite.*

(*a*) *Nephilinitoid* Basalt (Bořicky) is a basalt in whose (*m*) groundmass, instead of nepheline, is seen a colorless, grayish white, or yellowish white substance, which reacts like nepheline by polarized light, but is otherwise unlike it and greatly altered. In Bohemia. (This is a (*m*) distinction and cannot be made (*M*).

(*b*) *Noseanite* (Bořicky). A nosean-rich nepheline-basalt with coarse, medium, and fine states. In Bohemia, the Eifel, etc.

2. **LEUCITE**-basalt, Anamesite, and Dolerite.

A usually dark-gray, sometimes (*M*) fine-crystalline, rarely coarse-grained, usually microcrystalline to compact and slaggy groundmass composed of (*m*) leucite, augite, magnetite, and olivine, with or without glass base, and carrying (*m*) and sometimes (*M*) phenocrysts of augite and olivine, and rarely leucite.

Silica 40–47; Gr. 2.84–2.94.

It occurs as necks and lava-streams, especially developed and studied in the Eifel, Erzgebirge, about the lake of Laach, and in Hesse, Bohemia, Sardinia, Algiers, Persia, Australia, and New Zealand. As stated above, the doleritic state is rare, the anamesitic uncommon, and the basaltic cannot be readily told by inspection from feldspar-basalt, as leucite retreats to the (*m*) groundmass, which is rarely coarse enough to be resolved with the lens. Leucite occurs sometimes well crystallized, but usually irregular and rounded. In the groundmass it is ill defined, and thus differs (*m*) from its habit in tephrite. Augite and olivine occur as in other basalts. Nepheline, melilite, and haüyne are in varying amounts, and form transitions into the other basalts of the group. Sanidine and plagioclase cannot be very abundant without forming either leucite-*phonolite* or *basanite*. Biotite, apatite, and hornblende also occur (the last abundant in a few localities).

(*a*) *Leucitoid* Basalt (Bořicky). A companion to nephelinitoid basalt. Here leucite is not sharply defined, but seems to be present in irregular colorless patches in the interstitial spaces. In Bohemia.

(*b*) *Peperin-basalt* (Bořicky). A reddish brown to brown-

ish gray clayey or weathered groundmass composed (*m*) of augite, leucite, nepheline, magnetite, and rarely olivine, carrying large well-defined phenocrysts of augite, hornblende, and rubellan. It is found at Kostenblatt, Bohemia, and in a few neighboring localities. It is probably a hardened mud-tuff (whence the name).

3. **MELILITE**-basalt (Stelzner).

A usually greenish black (sometimes grayish black or grayish blue) fine-crystalline to compact groundmass, composed of (*m*) melilite, augite, and olivine, and carrying phenocrysts of (*M*) olivine and augite, rarely of melilite, and (*m*) of the same, with nepheline, magnetite, and apatite.

Silica 34–36; Gr. 2.89–3.04.

It occurs in small bosses; in dikes of small and medium size; in streams and tuffs. It is especially developed in Swabia; also in Bohemia, Saxony, Sweden, the Transvaal, etc., and in America at Ste. Anne, Canada, Manheim, N. Y., and Uvalde county, Tex. The honey-yellow melilite is generally well crystallized, and is sometimes large enough to be distinguished by the lens, but it is usually (*m*) and forms one-third of the whole rock. Augite and olivine as in the other basalts, and frequently the latter is the only (*M*) visible phenocryst. It is sometimes altered to serpentine. As accessories occur (*m*) a scattering of biotite laminæ; nepheline usually rare, but abundant in the Canadian rock; native copper is found now and then; picotite, haüyne, and hornblende are rare. This ultra-basic rock is found breaking through granite and other rocks of high acidity, so that it has not lost any acidity in so doing. It is sometimes drusy. Rosenbusch has named the dike-forms on the island of Alnö, Sweden, *alnöite*. Their mica (anomite) is arranged parallel to the selvages, as in cases already noted in micaceous

dikes. The Canadian rock also has anomite, and much nepheline and perofskite.

(There are no intrusives to this group.)

ALKALI-LIME-SODA SECTION.

GROUP 19. TEPHRITE-BASANITE.

IIa. TEPHRITE-BASANITE-THERALITE EXTRUSIVES.

(Necessary minerals: Feldspathoids, plagioclase, pyroxene, with or without olivine.)

(*a*) Without olivine, the *tephrites* (v. Fritsch).

1. Pyroxene, plagioclase, and nepheline, *Nepheline*-tephrite.
2. Haüyne, Haüyne-tephrite.
3. Pyroxene, plagioclase, and leucite, *Leucite*-tephrite.

(*b*) With olivine, the *Basanites* (Brongniart).

1. Pyroxene, plagioclase, olivine, and nepheline, *Nepheline*-basanite.
2. Pyroxene, plagioclase, olivine, and leucite, *Leucite*-basanite.

*a*1. **NEPHELINE**-tephrite

A generally fine-crystalline to compact (but sometimes coarse crystalline-granular and porous) groundmass, sometimes basaltic, and sometimes of greasy luster; light gray, grayish green, brownish gray; composed of (*m*) plagioclase, augite, and nepheline (sometimes with leucite), and more or less glass base. This is

sometimes clear of phenocrysts, and sometimes exhibits them of (*M*) size, of the components, with accessory hornblende, biotite, sanidine, and haüyne. Augite is green and brown, the former in the groundmass and the latter as phenocrysts. Hornblende and biotite are sometimes abundant and (*m*); sanidine is rare and scarce; haüyne is blue and yellow.

Silica 49–57; Gr. 2.62–2.75.

It occurs as lavas-streams, sheets, plugs, in Germany, Bohemia, Africa, Asia, the Canaries, Cape Verdes, and in the Peloncello Mountains, Ariz.

(*a*) *Buchonite* (Sandberger) is a variety with a (*m*) nepheline-plagioclase groundmass containing microlites of augite, carrying abundant long black prisms of hornblende, nepheline with greasy luster, (*M*) biotite and plagioclase, and sometimes orthoclase. Silica 54–84; Gr. 2.85. From the Rhone district (Buchonia). A hornblende-nepheline-tephrite.

(*b*) *Phonolite*-tephrite. A compact glimmering groundmass with greasy luster, composed of a moderate amount of plagioclase, considerable sanidine, scanty augite and hornblende, and carrying phenocrysts of sanidine and haüyne.

(*c*) *Tephritoid* (Bücking). A plagioclase-augite rock without olivine, in which nepheline cannot be recognized as a distinct mineral, but whose base seems to carry it, from its high soda content and its gelatinizing with acids.

a2. **HAÜYNE**-tephrite.

A dark-gray to black groundmass carrying phenocrysts (visible with lens) of labradorite, acicular hornblende, augite, dark-blue haüyne, or waxy-yellow nosean grains. The groundmass contains (*m*) augite in abundance, with titanite and apatite, seldom olivine. From La Banne d'Ordenche, and near the lake of Guéry, France.

*a*3. **LEUCITE**-tephrite.

A structure like nepheline-tephrite. Fresh and weathered, and altered to analcime. In a light-gray, bluish, or greenish gray groundmass (fine-grained to compact, and rich in glass base or without it) composed of (*m*) plagioclase (sometimes sanidine), small amounts of leucite, and sometimes nepheline, augite, magnetite, and apatite, are phenocrysts of leucite (sometimes of large size, and sometimes altered to analcime), plagioclase, sanidine, augite, nepheline, haüyne, hornblende, and quartz, and (*m*) melanite.

Silica 46–58; Gr. 2.57.

It occurs in lava-streams—infrequently in dikes—in Germany, Bohemia, Italy, East Indies. The leucite is usually in well-defined individual grains—no matter how minute it may be, and in this respect it differs from its habit in the basalts, where it is much more irregular and fills interstitial spaces in the groundmass.

(Hussak places here the rocks of Brazil, Cape Verdes, and at Deckertown, N. J., which carry large folia of biotite, and rounded bodies which are sometimes distinguished as analcime and sometimes as calcite. All of these rocks seem to have been metachemized, as the augite has uralitized, and the above rounded bodies are probably altered leucites.)

*b*1. **NEPHELINE**-basanite.

This rock varies between nepheline-basalt and nepheline-tephrite. It resembles basalt, and has a groundmass of (*m*) plagioclase in varying proportions, nepheline, augite, and olivine, and carries phenocrysts of the same. The groundmass may be (1) *basaltic* and black or brown, composed of much plagioclase, black augite, nepheline, and olivine, with small amounts of glass,

and not many accessory minerals, or (2) *tephritoid* and greenish, through change in augite, with magnetite and small amounts of feldspar, and carrying an abundance of accessories, as hornblende, biotite, titanite, haüyne, and sometimes sanidine, so that it becomes phonolite.

Silica 40–51; Gr. 2.90–3.15.

It occurs in the Eifel, in Bohemia, Cape Verdes, Canaries, South Africa, Japan, Uvalde County, Tex., Elk Mountains, Col., etc., in lava-flows, and weathers to a yellowish crust (somewhat like that of phonolite), and gelatinizes with HCl.

Basanitoid (Bücking). A compound of plagioclase, olivine, and augite, and with no perceptible nepheline, but with a base that gelatinizes with acids, like nepheline compounds, and has a high soda content. It occurs along the Rhone and south of the Thuringian Forest.

b2. **LEUCITE**-basanite, Leucitophyre (in part).

A similar rock with leucite replacing nepheline. In a glass base is a combination of (*m*) leucite, plagioclase, olivine, and magnetite. Leucite alone is commonly (*M*), sometimes green or black augite; the others rarely, and nepheline never. The texture varies from coarse-granular to compact in the same lava. This was formerly included with leucite-phonolite under the name *leucitophyre*.

Silica 47.64; Gr. 2.77–2.81.

It is the lava of Vesuvius, and also found in the Eifel, Brazil, Java, and lower California.

GROUP 20. THERALITE.

IIa. TEPHRITE-THERALITE INTRUSIVE.

(Necessary minerals: Feldspathoids, plagioclase, and pyroxene.)

THERALITE (Rosenbusch).

A granitoid to compact compound of augite, plagioclase, and nepheline, with olivine as accessory.

Silica 43.17; Gr. 2.93.

This occurs in dikes, bedded sheets, and laccoliths in the Crazy Mountains, Mont., and is the intrusive state of the tephrites that was looked for, and the name is given from the Greek verb "to be sought for." The augite is in prisms up to ¼ inch; biotite in sharp hexagonal tables; anorthoclase and nepheline in coarse-grained aggregates; olivine is (*M*) and rust-brown. In the largest laccolith the texture was granitoid in the middle and became compact at two feet from the walls, with columnar-jointed structure normal to them. There are porphyritic states of a dark green with phenocrysts of black augite, and abundant olivine and biotite. A similar rock has been noted on the Elbe.

Teschinite. Rosenbusch places this rock here as the leucite equivalent of theralite, as the analcime is its representative; but the microscope shows that this mineral has been formed at the expense of labradorite. For the description of the rock see under "Diabase."

GROUP 21. III*a*. BASALT-GABBRO EXTRUSIVES.

III. LIME-SODA SECTION.

(Necessary minerals; Plagioclase, pyroxene, olivine, magnetite.)

Following the analogy of the former divisions, this group will be separated, according to the predominant member of the necessary minerals, as follows:

1. Predominant plagioclase, *Plagioclase*-basalt, or ***basalt.***
2. Predominant olivine, ***Limburgite***, or ***magma***-basalt.
3. Predominant pyroxene, ***Augitite.***

DOLERITE (Haüy), "Deceptive."

ANAMESITE (v. Leonhard), "Intermediate."

BASALT (Agricola), **Feldspar**-basalt. (From the Latin *basaltes.*)

(*M*) dolerite is the coarse-grained, anamesite the medium fine-grained, and basalt the microcrystalline to compact state of a compound of (*M*) plagioclase and augite, with (*m*) magnetite, and olivine (*M*) and (*m*); also with neither nepheline nor leucite. All the states exhibit pores and vesicles, but the last is highly vesicular and amygdaloidal.

Silica, dolerite, 48–57; anamesite, 47–52; basalt, 40–51.

Gr. dolerite, 2.7–3; basalt, 2.9–3.1; average, 2.87.

The compound occurs widely distributed through the world as a basic lava, in surface and intrusive sheets, lava-streams, plugs, and dikes. In North America it covers extensive areas, and especially on the Pacific border, where it forms many "table mountains" and surface sheets many square miles in area. Basalt especially, and anamesite to a much less degree, are traversed by planes causing columnar and tabular jointing. This is especially the case near the margins of the flows. The columnar structure is well developed near Orange, N. J., on the Columbia River, Ore., and abroad at Fingal's Cave, the Giant's Causeway, in Australia, etc. The columns are straight or curved, and horizontal, vertical, or inclined, dependent on the direction of the flow, as the jointing is normal to the cooling surface,

whether that be the air or the dike- or bed-walls. This structure is caused by the contraction of the cooling mass, and is met with in dike-rocks and their walls. The tabular structure is similarly caused, and divides the columns near the selvages of the dikes. This is sometimes of "ball and socket" form, which is shown on a grand scale near San Francisco, Cal. This last is probably due to the same forces that cause spheroidal weathering. The number of sides to a column varies from three to eight. The "plugs" above mentioned are the filled up flues of extinct volcanoes.

The adjective "feldspar" is applied by many authorities to this mineral combination, to show that it does not contain nepheline nor leucite. In case a distinct comparison is made between the basalts, this may be necessary; but, as the original "basalt" contains that mineral, it can be termed "basalt," as the hornblende-syenite is simply "syenite." The other basalts are then *nepheline*-basalt, *leucite*-basalt, etc. The varying states (dolerite, anamesite, basalt) are due solely to differences in the rapidity of cooling, analogous to the differences in the crystalline texture of slowly and rapidly cooled abyssals. In a thick effusion of the mixture the interior will show the very coarse "dolerite," which will change through the medium grain of the same to the fine-grained "anamesite," and thence, as we near the top of the flow or the selvage of the dike, we find the grain becoming microcrystalline, and finally reach compact "basalt," where cooling was most rapid. The surfaces of lava-flows are characterized by vesicular, slaggy, and pumiceous states, as already noted; but the fluidity of the effused basalt is so great that some of the vesicles are large enough for the tallest man to stand erect and extend his arms without touching the interior, as in some Hawaiian flows. The lining of vesicles and the selvages of dike-basalt show vitreous states

(tachylite, hyalomelane), and infiltration into the vesicles of old lavas forms amygdaloidal structures.

As *dolerite* is coarse- to medium-grained, the principal components can be recognized (*M*). The fresh fracture shows a brilliant surface. The *plagioclase* is usually fresh and white or light gray, and occurs in tables, blades, irregular grains, and rarely in prisms. It is found as phenocrysts in the principal mass and in the cavities, and is usually labradorite, but varies more frequently to the bytownite-anorthite end of the series than to andesine. As phenocrysts it is sometimes an inch long. *Sanidine* occurs sporadically at times, generally (*m*), but sometimes (*M*), and half an inch long by one quarter wide (Löwenberg, where the transition between andesite and basalt has been noted). *Augite* occurs in stout brownish black columns or grains, sometimes in laths. It is brown, brownish red, and rarely green by transmitted light. In the groundmass it is seldom well crystallized. *Olivine* is rarely present in the well-crystallized states, except in Iceland, where it is reported to be occasionally as abundant as the augite, and of a semimetallic luster and greenish brown color. *Magnetite* is rarely visible to the eye in any of the rock states, but titaniferous magnetite appears (*M*) in large black folia, in some Hungarian rocks, and half a foot across. *Apatite* (*m*) is rare; large greenish-yellow or light brownish-yellow crystals of *hornblende* infrequent, and *quartz* rare.

As *anamesite* the components are generally fine-grained and require a lens for distinction. The same minerals occur, and in about the same proportion, except that olivine becomes more apparent (*m*) in the groundmass. We can detect the compound character by the naked eye, but find it hard to resolve it.

In *basalt* the conditions are different. The fresh rock (*M*) is microcrystalline (with the recognized glimmer on a

fresh fracture) to compact and homogeneous. The color is generally grayish to bluish black, seldom greenish black, dark green, or dark brown. In the South Mountain, on the border of Pennsylvania and Maryland, the ancient basalts are now pale green, and have been sheared into rocks which were thought to be slates until the late Dr. G. H. Williams demonstrated their igneous origin. The fracture is uneven, splintery, and coarse-conchoidal in the compact states. It often carries (*M*) phenocrysts of olivine, plagioclase, augite, and magnetite in crystalline grains, on fresh fractures the last shows metallic reflections of extreme minuteness. The groundmass varies from holocrystalline to a half-glassy state, and carries few phenocrysts in all the variations between granular and glassy. The altered augite forms green earth, chlorite, and calcite. Olivine is oil-green and in angular (*M*) and round grains. Hornblende generally as phenocrysts and (*M*), (sometimes $\frac{1}{4}$ inch), and yellowish brown (brown by transmitted light); this has already been noted in the description of other rocks as "basaltic hornblende." Biotite is (*M*) in phenocrysts. Some authorities note "hornblende" and "mica" varieties of basalt. Quartz is in (*M*) grains in Europe and most notably in the western United States, where many authorities have commented upon it. All agree that it is primary. In the "quartz-basalts" of this locality it is one of the oldest crystallizations, both (*M*) and (*m*), and is milk-white. Among the (*M*) accessories are zircon, bluish sapphire, blue cordierite in granular masses over two inches long, metallic iron (at Mount Washington, N. H., Isle of Disko (150 lbs.)), and an olivine compound, in irregular shapes and varying sizes, called "bombs." These last are peridotites, and are thought by some to be segregations of the magma, and by others to be pyroclasts, as they frequently exhibit sharp re-entering angles. They contain nepheline in nepheline-

basalts. In the cavities, cracks, and interior vesicles of basalt are numerous secondary minerals from metachemism, as quartz, chalcedony, hyalite, fire-opal, semi-opal, zeolites, carbonates, of lime, magnesia, iron, etc., barite, green earth, delessite, and chlorophæite. Epidote is rare. Native copper is found at Lake Superior and in the South Mountain of Pennsylvania and Maryland. The rock weathers to a rusty crust of lighter color than the interior, and the angular edges round by spheroidal weathering. This sometimes proceeds regularly inwards to form concentric shelly crusts when the rock is compact and not much jointed, and these can be separated with a hammer; sometimes weathering enters along the joint planes so as to form irregular polyhedra, that fall apart on fracturing, after the analogy of ball and socket jointing. In this case the weathering is uniform throughout. The state thus produced by the variations in color is called "spotted" or "granular" basalt. The first chemical change is in the formation of carbonate and oxide of iron, which, by loss of carbonic acid, become ferruginous tuffs and red clays. The varieties are:

1. *Quartz*-basalt (Diller), with large percentage of free quartz. From Lassens Peak, Cal., the Eureka district, Nev., Tewan Mountains, N. M., Santa Maria basin, Ariz., Anita Peak, Col., with a few localities in Europe where small amounts are found. The quartz is in milk-white grains with plagioclase, augite, and olivine. Iddings reports them as distinctly rounded, and suggests that they are the unabsorbed portion of the original mass, in which they were formed by the action of moisture. In the Tewan locality both quartzose and quartzless forms agree closely, with silica 52; the Lassens Peak variety shows silica 57.25.

2. *Hypersthene*-basalt (Diller). From Mount Thielson, Ore. A porous basalt with a groundmass rich in (*m*) dark-brown glass, and consisting of (*m*) plagioclase, augite,

magnetite, and apatite, carrying great phenocrysts of plagioclase, hypersthene, and olivine. Similar rocks are reported from Mount Pitt, Ore., and from San Salvador. A *bronzite*-basalt is reported from Greenland. Silica 55.68; Gr. 2.64–2.88.

3. *Parabasalt* (Zirkel), Olivineless Basalt. Carrying monoclinic and rhombic pyroxene and plagioclase, but without olivine, nepheline, or leucite. It occurs as dolerite, anamesite, and basalt, in Germany, Sardinia, Madagascar, etc.

4. *Analcimite* (Gemellaro). A highly vesicular basalt with large cavities and clefts in which analcime has been deposited through alteration in the rock, so that the greater portion of the mass is of this mineral. From the Cyclopean Islands.

Basalt Glass.

Here are grouped together all the glassy states of all the basalts noted, and of any mixture.

BASALT GLASS (Judd and Cole).

Tachylite (Breithaupt). An extrusive basic glass with conchoidal fracture, readily soluble in HCl (whence the name).

Hyalomelane (Haussmann). A similar glass not so affected by acids.

Both types are found in glassy states of all the basalts, so that they cannot be divided between them with any regularity. The names are valueless, except as showing that the glass sometimes dissolves, and sometimes resists the effect of the acid.

Silica 44–54; Gr. 2.5–2.7; water 6–7.

They form thin linings to vesicular cavities, thin crusts on lava-flows, and seldom occur in large masses, except in the Kilauea lavas, where—owing to the enormous extent of the crater—the cooling is exceptional, and it is there in quite

thick crusts as pumice. In one instance it is a dike one inch thick. The color varies from grayish white to black through olive-green and greenish black, blue to bluish black, or shades of brown. The structure is compact; it occurs only in small pieces, porous, slaggy, pumiceous, hairlike, perlitic, and porphyritic; when the last, the phenocrysts are (*m*). The fracture is conchoidal; fuses easily to a slaggy glass; hardness less than that of obsidian; magnetic, and generally opaque in the thinnest splinters. Owing to the failure to divide the basalt vitrophyres between tachylite and hyalomelane, Judd and Cole suggest "basalt glass" for all such states.

1. **Hydrotachylite** (Petersen). From Rossberg, Darmstadt. A somewhat weathered bottle-green to black glass, with greasy luster, conchoidal fracture, and usually clear of phenocrysts. Easily soluble in concentrated HCl; easily fusible. Silica 47.8; Gr. 2.103; H. 3. This is a state of nepheline-basalt which had silica as low as 40.53; Gr. 2.524; H. 5–6; and difficultly soluble in concentrated HCl.

2. **Leucite-basanite-perlite, Obsidian,** and **Pumice.** The Vesuvian lavas are crusted with these states. The glass is black and vitreous or pitchy, and yellowish brown by transmitted light, carrying spherules and phenocrysts of (*M*) leucite and augite. Porous white pumice comes from Monte Somma and Pompeii. Silica 47.8; Gr. 2.77. It is found in Italy, Java, Lower California.

LIMBURGITE (Rosenbusch), Magma-basalt (Bořicky).

A microcrystalline to compact basaltic groundmass carrying usually only (*M*) phenocrysts of olivine, sometimes of augite and hornblende, and composed of olivine, augite, and magnetite, with more or less glass base. As accessories occur nepheline, leucite, and plagioclase.

Silica 40–43; Gr. 2.83–2.97; water 2–5.

A rock, first found near Limburg, without a feldspathic mineral, which occurs like basalt extensively in Germany, Bohemia, Spain, Cape Verdes, South Africa, Portugal, Brazil, Greenland, etc. The augite is large and green, or small and light brown to yellow; hornblende is large; olivine is of the hyalosiderite type, with metallic luster and yellowish green to golden yellow color; the amount of glass varies; secondary minerals are carbonates, zeolites, chalcedony, and hyalite. There are two types:

1. *Feldspar*-magma-basalt, where the rock is not much affected by acids; is almost holocrystalline with a small amount of brown glass, and forms hyalomelane glass, analogous to the basalts.

2. *Feldspathoid* Magma-basalt, with abundant clear glass base; gelatinizes with HCl to form much NaCl on evaporation; forms glass of the tachylite type, and is analogous to the nepheline-basalts.

Verite (Osann), Mica-magma-basalt. From Vera, near Cabo de Gata, Spain, where it occurs as a lava-stream. (*M*) a black lava with pitchy luster; often amygdaloidal: carrying phenocrysts of brown mica in folia, visible (*M*) and readily with the lens. The groundmass is a glass rich in mica, olivine, diopside-like pyroxene, and some apatite. Silica 55.17.

AUGITITE (Doelter).

A black compound of augite, magnetite, and glass base. Silica 41–45.

This was first found as a lava in the Cape Verdes, and also occurs occasionally in Bohemia, Venezuela, France, Portugal, Brazil, etc. The glass base is either brown or yellow, and is soluble in HCl with slight difficulty; or it is colorless and readily soluble. Augite rarely forms large phenocrysts, but is usually a confused mixture of small yellowish or reddish prisms. Haüyne is sometimes accessory; plagioclase, nepheline, biotite, hornblende, apatite, specular hematite, and magnetite occur. It readily forms zeolites.

1. *Haüynetachylite* (Möhl), is a brown glass from the South Sea Islands, carrying the above, and is a glassy augitite.

2. *Ehrwaldite* (Cathrein). A greenish to grayish-black microcrystalline groundmass with black lustrous augite ¼ to 1½ inches; brown biotite to ¼ inch; brownish to dark-green phenocrysts of bronzite turned to bastite. The groundmass (*m*) is doleritic, and carries much basaltic hornblende, augite, rhombic pyroxene, biotite, apatite, and magnetite. It weathers to carbonates and zeolites. There is neither olivine nor nepheline.

GROUP 22. GABBROS.

IIIa. BASALT-GABBRO INTRUSIVES.

(Necessary minerals: Plagioclase, olivine, pyroxene, magnetite.)

These may be arranged according to the predominant mineral:

1. Plagioclase series, *Gabbros.*
2. Olivine series, *Peridotites.*
3. Pyroxene series, *Pyroxenites.*
4. Magnetite series, *Magnetites.*

GABBROS.

Combinations, varying from coarse granitoid to compact, of predominant plagioclase, a pyroxene, olivine, and magnetite in varying proportions. They can be divided, according to the size of their crystals, and their predominant mineral, into:

I. GRANITOID GABBROS:
- *a.* Plagioclase and diallage, *Gabbro;* with olivine, *Olivine*-gabbro.
- *b.* Plagioclase and rhombic pyroxene, *Norite;* with olivine, *Olivine*-norite.
- *c.* Plagioclase, *Anorthosites;* with olivine, *Troctolite.*

II. GRANULITIC GABBROS:
- *a.* Plagioclase and augite, *Diabase;* with olivine, *Olivine*-diabase.

III. GABBRO-PORPHYRITES:
- *a.* Plagioclase and rhombic pyroxene, *Norite*-porphyrite.
- *b.* Plagioclase and augite, *Diabase*-porphyrite.
- *c.* Plagioclase, *Labrador* porphyrite.
- *d.* Augite, *Augite*-porphyrite.

IV. MICROCRYSTALLINE GABBROS:
- *a.* Without olivine, *Aphanite.*
- *b.* With olivine, *Melaphyre.*

V. GABBRO GLASS:
- *a.* Gabbro glass.
- *b.* Diabase glass.
- *c.* Variolite.

Ia. **GABBRO** (Breislak), Diallagite (Descloiseaux), Granitone.

A holocrystalline, granitoid, equidimensional mixture of plagioclase and diallage, with magnetite, titanite, apatite, and olivine.

Silica 43–54; Gr. 2.8–3.2.

It occurs as masses, bosses, intrusive sheets, dikes, and surface sheets in Saxony, Silesia, the Harz, the Rhone district, Bohemia, the Alps, Italy, Spain, France, Great Britain, Norway, Sweden, Iceland, Japan, Africa, Australia, South America, Massachusetts, New Hampshire, Delaware, Mary-

wholly for its success upon the reducing gases passing upward through the charge, it is clear how im-

[1] Read by R. H. TRAUBE of Utah at the Salt Lake session of the International Mining Congress, July, '98, and specially reported for the MINING AND SCIENTIFIC PRESS.

land, New York, Colorado, about Lake Superior, California. The typical gabbro is very coarse-grained and granitoid, with predominant plagioclase. It also has fine-grained textures, seldom amorphous, and exhibits parallel (banded, striped, schistoid), fluidal and somewhat centric structures. Plagioclase is labradorite or anorthite (sometimes oligoclase, and even orthoclase with quartz), and is usually in isometric crystalline grains (sometimes two inches) of a grayish white color (sometimes brownish and bluish violet). The feldspars sometimes change to saussurite, as stated under the minerals, though it is also a compact zoisite or a form of garnet. Diallage is bladed, in irregular tables or in grains, colored gray, brown, oil-green, with strong metallic-pearly luster. The plates are sometimes three inches broad. It alters to grass-green smaragdite with pearly luster. Judd thinks diallage only a "schillered" augite, and the augite and rhombic pyroxene (enstatite) the primary forms of the group. Hornblende, rhombic pyroxene, and mica are frequent essentials and (*M*); as accessories are garnet, zircon (sometimes one inch long), pyrrhotite (not pyrite), and secondary calcite. The minerals crystallized at the same time and are generally hypidiomorphic. Olivine occurs (*M*) and is sometimes very abundant. It usually alters to other minerals (serpentine and chrysotile). The rock is usually poor in accessories. With predominant hornblende the rock is diorite; with rhombic pyroxene, a norite; with augite, a diabase. It cannot be traced into hypocrystalline nor porphyritic varieties, nor is it accompanied by tuffs.

1. *Zobtenite* (J. Roth). From the Zobtenberg, Silesia. A schistoid gabbro, which also has an olivine variety. A coarse- to fine-grained rock, also found on the selvages of gabbro eruptions, as is usually the case with mixtures of highly unequiaxial black minerals, and with parallel arrangement to the dike-walls.

2. *Beerbachite* (Chelius). A fine-granular dike-gabbro which also carries olivine, from the Melibocus, with silica 47. Hornblende sometimes replaces diallage.

3. *Odinite* (Chelius). From near Darmstadt in a dike, with silica 52. A gray groundmass carrying plagioclase and green to colorless augite with mica in the center of the dikes, which are coarse-grained there.

Hypersthene-gabbro, Gabbro-granite (Chester). From Delaware, where it contains accessory quartz, basaltic hornblende, and biotite. Hypersthene-gabbros also occur in the Odenwald, at Monzoni, etc.

Hornblende-gabbro (Chelius). From the Odenwald, Black Forest, Alsace, etc., with scanty diallage and abundant hornblende ($\frac{1}{8}$ to 2 inches). This is like diorite. In some of the localities the diallage has altered to hornblende by paramorphism.

1. *Smaragdite*-gabbro, with diallage altered to smaragdite, with grass-green color and pearly luster, and plagioclases not much changed to saussurite. At Mittleberg, etc.

(Some authorities place here the alteration products from diallage to hornblende, as the so-called "hyperite-diorites," etc. These have been described under "Diorite.")

Mica-gabbro. From the Brocken, Harz. A fine-grained rock rich in biotite and augite and poor in olivine. Quartz appears more frequently than in normal gabbro, as would be the case with micaceous rocks. It is found elsewhere as a variety in gabbro formations.

Orthoclase-gabbro (Irving). From Lake Superior, with orthoclase, oligoclase, apatite, diallage, and much basaltic hornblende. It is generally free from olivine and carries secondary quartz.

Saussurite-gabbro, Euphotide (Haüy). A rock from Italy, France, Sweden, etc., where plagioclase is altered to

saussurite and diallage to smaragdite, with titanite, chromite, pyrite, serpentine, and carbonates. Silica 43–50; Gr. 2.65–3.69; H. 2.5–3; fusibility 3–3.5, and more or less attacked by acids. The euphotide of Mont Rosa has Gr. 3.65; from Sweden, 3.60; from France, 2.69. As they have their diallage more or less changed, they are classed as saussurite-diallage-gabbro and saussurite-smaragdite-gabbro.

Olivine-gabbro (G. Rose). A gabbro containing (*M*) olivine in small blackish green grains, or its weathered equivalent (serpentine or chrysotile). It occurs in Scandinavia, Great Britain, Japan, Waterville and Mount Washington, N. H., Cortlandt, N. Y., Maryland, Minnesota, Iron Mountain, Col., St. John, N. B.

1. *Olivine-enstatite*-gabbro. From the Western Isles of Scotland; carrying olivine and enstatite.

I*b*. **NORITE** (Esmark).

A usually coarse- to fine-grained (sometimes granitoid, porphyritic, and ophitic) compound of plagioclase and a rhombic pyroxene (hypersthene, enstatite, bronzite), with diallage, hornblende, orthoclase, ilmenite, and magnetite, also olivine and quartz.

Silica 43–65; Gr. 2.8–3.1.

It occurs in widely extended masses in Laurentian formations—especially in Scandinavia and North America; also in dikes. It is found in New York, Pennsylvania, Delaware, Maryland, North Carolina. It is associated with beds of titaniferous magnetite, and some authorities see in this a segregation from a gabbroitic magma. The minerals appear as in gabbro, and orthoclase is sometimes two inches long. The typical norite has a highly basic plagioclase with enstatite or hypersthene, and with little diallage, hornblende, or biotite. A high percentage of quartz forms

quartz-norite, and of olivine, *olivine*-norite. A quartz-norite from Mount Hope, Md., carries orthoclase and blue quartz.

Hypersthene-norite, when hypersthene is the predominant mineral. This is found about Lake Superior, the Adirondacks, in Delaware, etc. Some authorities call this "hyperite," while others use that term for "augite-norite." This is a misnomer, as it is only a norite.

Monzonite. A variety of the above from Monzoni in the Tyrol. Name no longer used.

Bronzite-norite. A variety with bronzite, now embraced under the general term. From Finland.

Augite-norite. A compound of hypersthene, augite, biotite, reddish brown feldspar, fibrous diallage, with the first two equally prominent. Cortlandt, N. Y. Silica 55.

Mica-norite. A compound of magnetite, hypersthene, biotite (bent and twisted about large portions of feldspar), broken and bent plagioclase, and garnet. Schistoid by selvage action at Cortlandt, N. Y.

Hornblende-norite. A transition between norite and diorite. From the Alps.

Spheroidal Norite, Ball Gabbro, "Potato-stone." From Romsås, with thick-shelled greenish brown concretions (up to six inches diameter) of biotite flakes and hypersthene, in a light-colored groundmass of labradorite, oligoclase, biotite, and magnetite; also at Cortlandt, N. Y.

Ic. ANORTHOSITE (F. D. Adams).

A gabbro with predominant feldspar (anorthite) to the almost entire exclusion of all other ingredients.

The plagioclase is frequently 95 per cent of the rock, and none of the essentials or accessories are ever abundant, such as hyperite, augite, hornblende, biotite, titanite, and magnetite. It occurs extensively in the Laurentian of New York, Canada, about Lake Superior, Labrador, and Newfoundland.

1. *Forellenstein*, Troctolite (Bonney). A gabbro composed of olivine and plagioclase. The olivine is altered to serpentine. There is little or no diallage. From the vicinity of Neurode, where it has the local name given above; but the contrast of the spots of blackish green serpentine grains against the snow-white feldspar led Bonney to call it as above given from its resemblance to the sides of a trout. The plagioclase is always like anorthite. Silica 41.13; Gr. 2.88. Found in Canada.

2. *Ossipyt* (Hitchcock) is a similar rock from Ossipee, N. H., with labradorite, olivine, magnetite, and an amphibole.

(This series is the "complement" of magnetite in the differentiation of a gabbroitic magma.)

GRANULAR GABBRO.

IIa. DIABASE (Haussmann).

A coarse- to fine-grained and usually compact and ophitic greenish compound of plagioclase, augite, and generally viridite, with specks of ores and accessory biotite, rhombic pyroxene (usually (*m*)), olivine as in gabbro; quartz occasionally (*m*).

Silica 43–56; quartz-diabase 53–58; Gr. 2.8–3.

It occurs as surface and intrusive sheets and beds, and as dikes, and joints and weathers like basalt. A locality on the shore of Lake Superior in a width of 14 inches exhibits 28 intrusions of diabase into granite; so that 27 granite plates, varying in thickness from $\frac{1}{4}$ inch to 8 inches, lie between them. It is abundantly developed throughout the world, and especially in the Trias of the Atlantic border of the United States. It is usually fine-grained and frequently aphanitic and porphyritic; also schistose; parallel structures; variolitic, and amygdaloidal. The cavities of the rock in the last state are filled with quartz, actinolite, asbestus,

pistacite, cat's-eye, axinite, calcite, dolomite, native copper, and zeolites. The diabase-*porphyrites* are in small dikes or the selvages of great ones. It also shows tuffs. Olivine is variable. Plagioclase is oligoclase, labradorite, bytownite, and anorthite; tabular, lath-shaped, and regular; white, grayish white, and greenish white. Augite is brownish to brownish black as idiomorphs, irregular grains, and slender laths; quartz and orthoclase are (*m*); biotite is usually in the hornblendic varieties of coarse grain. Augite alters to chlorite, serpentine, and uralite. Viridite occasionally is in (*M*) folia. It colors the rock. Epidote is also a secondary product. The color is usually green. The Washoe diabase is blue when freshly blasted; in a minute it shows brownish shades, and in five minutes it is entirely brown. When in dikes and masses, diabase is frequently altered to schists by squeezing. Barus fused a diabase with Gr. 3.0178 to a glass with Gr. 2.717, and argues that the original density is due to pressure during solidification.

1. *Leucophyre* (Gümbel). From the Fichtelgebirge. A light-colored saussurite-like rock with green augite, colored by viridite, and carrying titanite, plagioclase, piedmontite, augite (either green or brown), scanty hornblende. Silica 71.

2. *Proterobase* (Gümbel). From the same locality, and meaning an older rock than the others. It carries primary basaltic hornblende. A later rock is called *hysterobase*.

3. *Algovite* (Reiser). A granular to compact dark-green to reddish brown amygdaloidal and porphyritic rock with great plagioclases. The only (*M*) minerals are plagioclase and light-brown augite.

4. Diabase-*pegmatite* (Brögger). From Brandbokampus, Norway, and composed of augite, basaltic hornblende, and titanite in large grains, with very basic plagioclase, in dikes where large crystals are formed like pegmatite, of plagioclase with hornblende and augite playing the rôle of quartz.

5. *Calcareous* Diabase. This is no longer known as a separate rock, as the calcite, in any case, is a secondary product. There were states of this called calcareous aphanite and schalstein.

Sahlite-diabase (Törnebohm). From Sweden, England. Idiomorphic diopside-like augite with frequent quartz. Also in the Trias sandstone of the Connecticut Valley.

Enstatite (Bronzite)-diabase (Rosenbusch). From Saar-Nahe district, Sweden, England. A hypersthene-diabase is found in New Jersey, Virginia, etc.

Uralite-diabase. From the Schwarzwald, Harz, Cyprus, Sweden, the iron region of Michigan. This is distinct from hornblendic proterobase. A medium-grained compound of bytownite, large fibrous prisms of uralitized pyroxene, compact grains of hornblende, and biotite. It alters to epidote and chlorite. It is widely scattered throughout the world, with diabase, but of limited occurrence at any one place. It is accompanied by garnet in Michigan.

Mica-diabase (Emerson). In dikes at Franklin, N. J. It is spherulitic, with small pyroclasts of fused willemite from the dike-walls through which it broke. It is composed of labradorite, augite, biotite, apatite, and titanite.

Ophite (Palassou). From the Pyrenees, Spain, Portugal. A coarse-grained to (*M*) dense and seldom porphyritic rock, light- and dark-green to black. Gr. 2.7–3; silica 49.50. It occurs as dome-shaped masses and dikes. It is a uralitized diabase with columnar jointing and spheroidal weathering, so that concentric shells can be removed as in the case of basalt. (*M*) plagioclase and augite are not abundant; secondary calcite occurs in veins, and some kinds effervesce with acids.

Teschenite (Hohenegger). In irregular masses, apophyses, and dikes. From eastern Silesia. A felsitic rock with

intersertal texture in which hornblende forms long black acicular crystals of basaltic type; apatite the same at times. Named from Austrian Silesia (Teschen). Plagioclase is labradorite-bytownite-anorthite; augite (*M*); ilmenite; scanty biotite. When coarse-grained, hornblende and augite are in (*M*) individuals. Analcite is abundant, and on this account Rosenbusch places this with theralite, as another combination of plagioclase-feldspathoid rock; but Zirkel states that the microscope shows that the last mineral is formed at the expense of labradorite, and not from a possible nepheline or leucite. It occurs (*M*). Chlorite and calcite are secondary.

Olivine-diabase. Silica 48.18; Gr. 2.93–3.19. It occurs in dikes in Germany, Sweden, Great Britain, Asia, South Africa, Brazil, in the United States in Minnesota, Deerfield, Mass., Campton, N. H., Kennebunkport, Me., Orange, N. J., Nevada. Olivine is partly fresh and partly opalized and serpentinized; augite is partly like diallage; hornblende and biotite are (*M*) in the coarse-grained states to a higher degree than in diabase; and much hornblende forms *olivine*-proterobase. Plagioclase is usually labradorite; anorthite forms the variety *eukrite* (with little olivine and biotite, but much magnetite); orthoclase is found in large Carlsbad twins at Falkenstein, Saxony (two inches long). The texture varies from granitoid to ophitic, compact, vesicular, and slaggy; in beds, extrusive and intrusive sheets, and dikes.

PORPHYRITES OF THE GABBRO GROUP.

III*a*. **NORITE**-porphyrite.

A half-glassy rock with porphyritic structure; pitchy luster; carrying small phenocrysts of rhombic pyroxene and (*M*) plagioclase; without quartz, hornblende, or biotite.

Silica 56–60; Gr. 2.7–3.

A scarce rock, associated with norite, and only possible

where rhombic pyroxene is abundant. It is called *enstatite*-porphyrite, *hyperite*-porphyrite, etc., as the pyroxenic mineral changes, and *olivine*-norite-porphyrite, when olivine also appears as phenocrysts.

Hypersthene-quartz-porphyrite (Lossen). From Elbingerode, as a hornstone-like groundmass with (*M*) phenocrysts of plagioclase, hypersthene, small quartzes, and sporadic garnet; orthoclase is (*m*); also biotite, apatite, and zircon. Silica 69.94.

III*b*. **DIABASE**-porphyrite (Rosenbusch).

A holocrystalline groundmass (*m*), carrying (*M*) phenocrysts of labradorite and augite.

Silica 43–58; Gr. 2.9.

The following porphyrites occur in dikes, as selvages to diabases, in Saxony, Thuringian Forest, Harz, Nassau, Saar-Nahe district, Vosges, Greece, Bulgaria, Switzerland, Italy, Great Britain, Sweden, Asia, Egypt, Victoria, in United States about Lake Superior. They joint and weather like diabase and basalt. Plagioclase is white to greenish white, usually ¼ inch long (rarely 1½ inches), and generally altered and stained with chlorite and epidote; augite is in stout prisms, greenish, greenish brown, and black, and pitch-black (all in the same fragment); quartz (*m*). The groundmass is greenish gray to blackish green; seldom brownish black or reddish violet; when fresh gives the microcrystalline glimmer; sometimes there is a small amount of (*m*) glass base; drusy, amygdaloidal (filled with calcite, quartz, chalcedony, cat's-eye, epidote, axinite, and zeolites).

Black Porphyry (Streng). From Elbingerode, Harz, with a black groundmass carrying (*M*) phenocrysts of labradorite and small prisms of augite, with accessory mica in brownish black folia, pyrite, and magnetite. The groundmass is seen to be crystalline by the lens.

III*c.* **LABRADOR** Porphyrite (Delesse).

A compact grayish green, dark-green, even reddish-violet groundmass, with phenocrysts of greenish labradorite in tables from one-third to two-thirds of an inch long, and rarely small augites.

Silica 54; Gr. 2.77; water 2.5.

The general occurrence and character are as described under "Diabase-porphyrite." It is found at Duluth, Wis., and Taylor's Falls, Minn. The varieties are:

1. *Cuselite* (Rosenbusch), with bluish gray groundmass carrying $\frac{1}{8}$ inch plagioclase and chloritic grains. Silica 58.02.

2. *Porfido-verde-antico.* From Laconia, Greece, Great Britain, etc. An olive-green groundmass which becomes lighter on heating, carrying dark-green augite and greenish white labradorite phenocrysts. Silica 53; Gr. 2.91. Epidote, chlorite, and quartz are secondary.

III*d.* **AUGITE**-porphyrite.

A compact dark-green matrix carrying phenocrysts of augite of $\frac{1}{2}$ inch and over.

Silica 42–49; Gr. 2.9.

Abundant as dikes and lava-streams in the Alps, with vesicular and amygdaloidal states common. There are placed as varieties:

1. *Uralite*-porphyry (G. Rose). First described from the Urals, with a dense greenish gray groundmass (sometimes blackish gray carrying phenocrysts of plagioclase from 1 to $1\frac{1}{2}$ inch, and uralite). Silica 61; Gr. 3.

2. *Mica*-augite-porphyrite. From England, with abundant folia of mica and augite. Silica 48–51; Gr. 2.57.

MICROCRYSTALLINE GABBROS.

IV*a*. **APHANITE** ("Unresolvable").

This is a compact state of the gabbro group, and in hand specimens can only be divided into the diabase and other forms by the presence of a few phenocrysts, which are not sufficiently important to form a porphyrite. It may be taken as the groundmass of the porphyrites, and varies from microcrystalline to compact (*m*), but with small amount of glass base. When it becomes glassy, it falls under the next division of the group. We can distinguish only norite and diabase-aphanites, as gabbro cannot yet be reported in compact or porphyritic states, and norite rarely.

I. **Norite**-aphanite is reported from Fifeshire, Scotland. A compact grayish-black rock associated with norite there.

II. **Diabase**-aphanite.

A (*M*) compact diabase without phenocrysts, forming an apparently homogeneous mass, dark green to black, as hard as feldspar; dull luster, subconchoidal fracture; sometimes slightly porphyritic, vesicular, amygdaloidal, and slaty.

Silica 43–58; Gr. 2.6–3.

This is associated with diabase; joints and weathers like basalt. Phenocrysts of augite or plagioclase in predominance form those varieties of porphyrite. It bears to diabase the relation that felsite does to granite. Some authorities see in this a highly devitrified diabase glass.

1. *Calcareous* Aphanite, Kalkaphanit. An aphanitic mass carrying abundant spherules of calcite, which are not the fillings of amygdules.

2. *Amygdaloidal* Aphanite, Spilite, where the calcite, quartz, or other minerals are the filling of amygdules. The French geologists call this *spilite*.

(NOTE on diabase rocks. Many geologists make no distinction between diabase and dolerite, other than that of color and difference in age. They both contain the same mixtures and appear in the same states. The color is said to be due to the formation of viridite, and the greater abundance in amygdaloidal states in diabase is due to greater age and exposure to metachemic agents. Others note that there are diabases without viridite, which seem to be older forms of augite-andesite. There is also a difference in texture in diabase and dolerite, which may be due to longer exposure to the above-named agencies. At any rate, both are placed in the group of gabbros, and are most intimately associated.)

IV*b*. **MELAPHYRE** (Brongniart).

A compact half-pitchy black, green, red, brown, bluish purple groundmass, weathering to brown, red, and green, composed of (*m*) plagioclase, pyroxene, and olivine, and carrying at times phenocrysts, which are usually olivine (sometimes $\frac{1}{10}$ inch, and usually visible with a lens). It is associated in Scotland with augite-andesites, and is thought by some to be an olivine variation of them; by the majority of petrographers, as an olivine variation of basalt and aphanite.

Silica 51–57; Gr. 2.68–2.85.

It occurs in beds, sheets, dikes, bosses, and pyramidal masses in Silesia, Thuringian Forest, Saxony, Bohemia, Great Britain, France, Hungary, the Alps, Spain, Greece, South Africa; in the United States at Keweenaw Point, Lake Superior, Nevada, Kennebunkport, Me. It joints irregularly in columns, tables, etc., and when weathered is full of ferrite, epidote, calcite, etc. A number of varieties are made on (*m*) variations of groundmass.

With this rock, when amygdaloidal, are associated native copper (Lake Superior), silver (the same), zinc ores, jasper,

chalcedony, agate, amethyst, calcite, etc., in abundance, never with zeolites, so that the Oberstein rock was worked for agate till exhausted. *Epidosite* is an epidotized variety.

Navite (Rosenbusch) is a red groundmass carrying phenocrysts of plagioclase and olivine. From Oberstein.

V. GABBRO GLASS.

With the exception of diabase, these are not very abundant, as the rocks are very basic and do not easily form such states, as their low heat content, in proportion to their great fluidity, allows them to form stony states under conditions where the acid rocks would only form glasses. The occurrence of gabbro is given as a probable gabbro glass. No norite-glass is reported as yet.

(*a*) **Gabbro** Glass. From Carrock Fell, England, in a dike one inch thick, traversing gabbro, and reported as probably part of it, as shown by its high specific gravity (2.99). A greenish to purplish glass, weathering yellowish brown; waxy luster; slightly magnetic; H. 6.5; silica 51-53; fuses to a black enamel on thin splinters.

(*b*) **Diabase** Glass. In some cases this is simply the extension of the glass base that is found in some diabases; in others it is a regular glass, with greasy luster, occurring with diabase, and forming pitchstone, pitchstone-porphyry, and obsidian states. Silica 44–55; Gr. 2.4–2.6. Near Quotshausen the diabase stream (extrusive) is fresh and has a glass crust with phenocrysts of altered olivine. It is also found on the selvages of dikes in Scotland, and in one or two instances in America; also in Sweden (see below).

1. *Wichtisite* (Törnebohm). From Finland, in considerable masses; black; slight luster; conchoidal fracture; hardness 6.5; Gr. 3.03; fusible to a black enamel; silica 54–56; in a dike 4–5 inches wide at Wichtis.

2. *Sordawalite* (Törnebohm). From Sordawala, in inch selvages to a narrow dike in hornblende-schists. It is black, like anthracite; vitreo-greasy luster. H. 4–4.5; Gr. 2.55–2.62; silica 47–49.

(*c*) **Variolite,** Jadeglanduleux (Brongniart). A light- to dark-green devitrified spherulitic gabbro glass, with silica 52.79; Gr. 2.896. Found in England, Ireland, Sweden, Silesia, Siberia, France, Thuringian Forest, Fichtelgebirge, Italy. Weathers and joints spheroidally; carries abundant greenish white to violet-gray spherules with radial-fibrous and concentric-shelly structure of a *silicate* which are so firmly intergrown in the mass that they do not separate on weathering, but, being more resistant than the groundmass, are left projecting above the surface as brown pustules (whence the name). Cole and Gregory on studying the occurrence at Mount Genevre decided that the rock was a devitrified tachylite with spherules. This rock must not be confused with amygdaloidal forms of aphanite, where the spherules are calcite; nor with the amygdaloidal forms of melaphyre, where they are silica.

BASALT-GABBRO INTRUSIVES.

II. OLIVINE SERIES.

(Necessary mineral: Olivine.)

PERIDOTITE (Rosenbusch).

These massive holocrystalline rocks are plagioclaseless gabbros with predominant olivine. Silica 26–45. Zirkel objects to the name "peridotite," as in some cases the mineral is not olivine, but one of its varieties; but the term is in general use, and is understood as a series with an olivine mineral predominant. According to the other component or components, the rocks are called:

(*a*) **Dunite** (v. Hochstetter). An olivine rock, generally with chromite. From Dun Mountain, New Zealand. An almost pure aggregate of olivine of characteristic color, angular grains, splintery fracture, and vitreo-greasy luster. Silica 42–43; Gr. 3–3.3. This is also found in Japan, the Western Isles of Scotland, and in a dike near Willard, Ky., with abundant garnet. It serpentinizes.

(*b*) **Picrite** (Tschermak). A compound of olivine and augite, named from the abundance of magnesia ("bitter") salt in it (Greek *pikros*). In dikes and beds in Austria, England, Scotland; in United States in Arkansas (Murfreesborough), Deer Island, Maine, Cortlandt, N. Y. In England it is reported as passing into diorite. It is mainly of olivine, and the rest a compound of augite, hornblende, and magnetite; blackish green in many cases, and almost compact with olivine in phenocrysts half an inch long. Olivine serpentinizes, as usual, in many cases. Silica 38.9; Gr. 2.96. It forms porphyritic states. *Kimberlite* (Carvall-Lewis) is a similar rock from Kimberly, South Africa, at the diamond mines; and *palæopicrite* (Gümbel) ("old picrite") is a serpentinized form with abundant chlorite in the Fichtelgebirge.

(*c*) **Eulysite** (Erdmann). A probably metamorphic compound of fayalite (iron-olivine) green augite, and pyrope, in lenticules in granulite near Tunaberg, Sweden; with thin-jointed structure. It is of limited extent.

(*d*) **Wehrlite** (v. Kobell). A dark-colored, coarse-grained mixture of fresh olivine and green diallage, with abundant basaltic hornblende and titaniferous magnetite. From Hungary, Bosnia, Finland, Scotland, Borneo, Japan.

(*e*) **Saxonite** (Wadsworth). A compound of serpentinized olivine and rhombic pyroxene (enstatite or bronzite); also called "schiller rock," from the alteration of the pyroxene to bastite. Silica 41.48. It is rarely found with fresh olivine. It occurs from the Baste, near Harzburg, and obtained the

name "harzburgite" from Rosenbusch, which is later than that given above. It is found in the Alps, Sweden, Borneo, New Zealand, and in the United States in Maryland with bronzite. Silica 43, and Gr. 3.022. *Buchnerite* (Wadsworth) is a similar compound with additional augite.

(*f*) **Lherzolite** (de Lamétherie). From L'herz in the Pyrenees. A coarse- to fine-grained and compact compound of olivine, diopside (grass-green and like diallage), enstatite, and accessory picotite. Silica 40–44; Gr. 3.3–3.4. In some cases it is so compact as to appear as a monotonously colored serpentine. Diopside in grains; enstatite yellowish brown to greenish gray with fibrous cleavage; picotite is small and black. It occurs in great sheets in the Pyrenees, Italy, Norway, Tyrol, Spain, Maryland, and at Mont Diablo, Cal. In Italy and Norway it is fresh; in Germany, France, and Cornwall more or less completely altered to serpentine, the olivine going first, enstatite next, diopside last.

(*g*) **Cortlandtite** (G. H. Williams). This is Bonney's "hornblende-picrite," and is a compound of olivine, hornblende, and augite, and is named from Cortlandt, N. Y., where it occurs in dikes. It also is found in Australia, Sumatra, Custer County, Col. G. H. Williams suggested that the previous name "hudsonite" (Cohen) be given to the augite-picrite type, while "cortlandtite" be used for the hornblende variety, and Rosenbusch and Zirkel have adopted the same.

(*h*) **Scyelite** (Judd). From Loch Scye, Scotland, is a mixture of (*m*) olivine-green hornblende and biotite.

(*i*) **Biotite**-olivine Rock (Koch). A compound of fresh olivine and great folia of biotite, rounded grains of spinel of dark bluish green, titaniferous-magnetite, accessory apatite and plagioclase. Silica 33–35; Gr. 3.27. From Crittenden County, Ky., DeWitt, Ithaca, N. Y.

BASALT-GABBRO INTRUSIVES.

III. PYROXENE SERIES.

(Necessary mineral: Pyroxene.)

PYROXENITE (Hunt), a general name for an eruptive granular rock consisting of one or more members of this mineral group, and equivalent to a gabbro without plagioclase or olivine. Silica 50–55; Gr. 3–3.4. The name has nothing to do with the pyroxenite of Coquand, which refers to a malacolite rock in granular limestone, and is wholly metamorphic. Rocks of this group are reported from Maryland, North Carolina, and elsewhere. That from Maryland consists of diallage and bronzite.

The late G. H. Williams suggested the following classification:

With augite, *Pyroxenite.* From Cortlandt, N. Y., Sierra Nevada, Cal.

With diallage, *Diallagite.* (See p. 235.)

With bronzite, *Bronzitite.*

With enstatite and diallage, *Websterite.* From North Carolina, Italy, etc.

IV. MAGNETITE SERIES.

(Necessary mineral: Magnetite.)

While magnetite is generally placed as a metamorphic rock from contact action, there are many cases where it is a distinct differentiation of a gabbro magma with or without other typical minerals as accessory. Many authorities hold that, as magnetite loses its magnetism at high temperatures, it could not thus be formed. It may be answered that there would be the same argument against its presence in basalt

and other truly eruptive rocks. This series does not propose to claim for all magnetites an eruptive origin, but many of them have a decided one, as the differentiation of a gabbro magma that has its antithesis in anorthosite. Magnetite and anorthosite are therefore "complementary" rocks. The variations thus far noted are:

(*a*) *Magnetite-olivenite* (Sjögren). From Taberg, Sweden, composed of magnetite and olivine with a small amount of plagioclase, with accessory mica and apatite. Here it is a distinct differentiation of a hypersthene-gabbro.

(*b*) *Plagioclase-pyroxene*-magnetite. Similar differentiations. From the Odenwald, Frankenstein, etc.

(*c*) *Plagioclase-olivine*-magnetite, Cumberlandite (Wadsworth). From Cumberland, R. I.; with silica 21; with feldspar as phenocrysts.

(*d*) *Pyroxene*-magnetite, Jacupirangite (Derby).

(*e*) *Nepheline-olivine*-jacupirangite. Both from Brazil, as differentiations of dikes.

APPENDIX TO GABBRO.

SERPENTINE.

Here are assembled entirely altered rocks which may have originally consisted of olivine, diorite, or gabbro, as these rocks pass (including all their ingredients) into this mineral, as seen along the juncture of the hornblendic gneiss and Potsdam quartzite at South Bethlehem and at Easton on the northern border of the South Mountain in Pennsylvania. It is therefore found in beds where it has formed from metamorphic rocks, and in dikes where it comes from those decidedly eruptive. Under the olivine series are given a number of instances of the latter change.

SERPENTINE.

A compact rock, dull in fresh fracture, soft, with greasy feel; usually dark green or brown.

Gr. 2.5–2.7.

It occurs compact, porphyritic (with crystals of pyrope), slaty, and veined. As accessories occur pyrope, talc, bronzite, chlorite, mica, magnetite, etc. Serpentine is classed among the peridotites from their habit of weathering, though it is derived from augitic and hornblendic rocks through a similar process. The serpentine-quartz rock at South Bethlehem, Pa., between the gneiss of the South Mountain and the overlying Potsdam quartzite, has been derived from the lower rock through change in the hornblende.

SECONDARY ROCKS.

In contrast with primary rocks, which have been formed by one continuous process from a fluid magma, *secondary* rocks are those which have been formed from pre-existing rocks, and which show by texture or structure, or both, such a derivation; or they are aggregates of chemical or organic forces through which the weathered or soluble portions of older rocks are gathered into masses. All of these can be distinguished from the rocks already described by the microscope, if not by the eye, though there are transitions in certain cases that will be impossible to classify without the microscope.

The tendency in nature is to stable compounds. The rotting of vegetation and the decay of nitrogenous bodies are paralleled in the "weathering" of rocks. In all these there is a change from a less to a more stable compound, and, be the process short or long, there will ultimately be reached a compound stable under a continuation of the circumstances which formed it. These circumstances do not, however, remain continuous, and the constant variations in nature tend to new combinations. A good example is seen in the action of the oxides of iron. Most waters after soaking through the earth's crust, especially in volcanic regions, have minute percentages of sulphuric acid, which dissolves whatever protoxides of iron are met with and carries the solution into the bodies of water on the earth's surface. The protoxide at the surface of the water becomes hy-

drated sesquioxide, which is no longer soluble in the acid, but falls to the bottom of the liquid to take oxygen to whatever organic bodies may be there, and, being reduced, is again soluble and brought to the surface, to renew the operation. This is but a short cycle of changes; others may require centuries to complete. In the previous pages minerals have been noted as undergoing "alteration" and forming "secondary" minerals, and these, in their turn, have been broken up to make more stable forms—as the black bisilicates pass through viridite, epidote, carbonates, opacite, or ferrite, to form ferruginous clays; while feldspars, through other lines of alteration, form lighter clays. Quartzose rocks, after the weathering and levigation of their unstable compounds, are reduced to "granular" quartz sand. When weathering outstrips denudation, the rocks will have made these changes, or have lost their cementing media to great depths, as in Brazil, where the elder Agassiz reported weathering at a depth of 150 feet. Incipient weathering proceeds to great depths even in temperate latitudes, as Callon states that in Europe it is usually necessary to strip away 80 feet of slate outcrop before finding workable stone. This is for unglaciated regions; but in the slate belt of Pennsylvania, which was covered by the furthest and earliest of the ice advances, the average of "mucking" is but 10 feet, and near Treichler's, Pa., workable slate lies directly underneath glacial gravel. Other good examples of the slowness of weathering are shown in the anthracite-coal basins around and south of Hazelton, which were also covered by the earliest ice advance. It is only in these regions that it is profitable to "strip" the surface, and throughout these regions anthracite coal is mined and sold with no covering but glacial gravel. On the other hand, the loss of cementing material proceeds to great depths. In the iron (limestone) ores of the Clinton formation, north

of Danville, Pa., the cementing calcite has been removed over large areas for 500–700 feet from the outcrop of the beds, and deeper along the numerous faults that intersect the region. The slight variation in dip of surface and bed makes this average 40–60 feet below the surface, and the removal has been so complete that the bed can be worked with an ordinary pick or hoe, and the overlying shales have lost their consistency and are readily cut with a pick, unless extremely siliceous. We thus see that weathering produces large masses of decomposed rock in place, and a comparison of fresh and weathered rock shows us that the primary rocks have lost their alkalies and soluble acids; while the quartz and aluminous silicates remain. We must be prepared, therefore, to find these stable compounds predominant in secondary rocks, unless changes have formed new compounds. Denudation tends to remove these accumulated masses and distribute them under water in lakes or along seaboards. The study of orogenic movements shows us that these sediments may be transformed into a new series of "metamorphic" rocks, and that, by similar movements, the primary rocks may be similarly changed without undergoing weathering and denudation. A third class of rocks is formed by chemical precipitates from saturated solutions; but this is inconsiderable in varieties of rocks or bulk. A fourth class is due to the secretive power of organisms; a fifth to the forces acting on the country-rocks during eruption or orogenic movements, by which comminution is produced, etc. All of these can be grouped under two heads, whether the masses retain their original state of aggregation (subject to minor changes that do not constitute metamorphism), or whether they have been metamorphosed, as:

I. *Automorphic* Aggregates.

II. *Metamorphic* Aggregates.

I. AUTOMORPHIC AGGREGATES.

In this group the changes subsequent to aggregation must be simple and due to pressure without great heat or other non-metamorphic agencies of consolidation. The causes of aggregation are *mechanical*, *chemical*, and *organic*. In each of the classes the predominant force will be one of these three; but this does not presuppose that either or both of the others cannot enter in a subordinate manner.

Mechanical Aggregates, Fragmental Rocks. These are formed and gathered by the mechanical forces of nature from the broken (clastic) fragments of older rocks, without predominant chemical or organic action. The forces producing the comminution and, to a great extent, the aggregation are:

(*A*) *Hydrogenic*, or due to water in forcing apart (through frost) the rocks and comminuting the fragments: grinding these during transportation and sorting them.

(*B*) *Pyrogenic*, or due to the eruptive forces which act upon the walls of fissures, or which produce finely comminuted fragments of primary rocks.

(*C*) *Orogenic*, or due to the crushing effect of earth movements.

(A) Hydrogenic Aggregates.

These can be divided according to the manner in which they were assembled by water, whether by the liquid or solid state, as:

1. *Aqueous*, where the assemblage was caused by rain, streams, etc.; and

(*a*) *Unsorted Débris*, where the aggregation is due to rain, melting snow, or the undermining of areas through solution;

(*b*) *Stratified Deposits*, where the sorting and transporting power of water have assembled the mass.

2. *Glacial*, where the assemblage was caused by ice in the form of glaciers, and by its ablation.

(NOTE. With the aqueous rocks will be noted the similar forms produced by *Æolian* forces, as they resemble them lithologically.)

(B) Pyrogenic Aggregates.

1. *Pyroclasts*, when the fragments have been torn from the sides of the fissures through which the eruption was made, or formed from the eruptive itself.

2. *Tuffs*, when consisting of eruptive ash, which has been subsequently compacted to a greater or less degree, and more or less altered.

(C) Orogenic Aggregates.

Oroclastic Breccias, when formed by orogenic movements.

UNSORTED DÉBRIS.

The want of stratification that characterizes these deposits is also possessed by glacial aggregates, especially the stranded lateral moraines on the sides of valleys, which are accumulations of the same ultimate origin that have been moved further down the valley. The ordinary moraine-stuff can be distinguished from these deposits by the presence of rocks foreign to the neighborhood in the absence of distinct marks of glaciation in the mass. Another unfailing distinction is in the relative freshness of the mass from top to bottom of a vertical section. Unsorted débris is most weathered at the surface, where atmospheric agents have unrestrained action, and possesses greater freshness towards the bottom of the section, where the solid rock is met with. Glacial accumulations, on the contrary, have been turned over and thoroughly mixed, and the time of accumulation has been small with respect to the rate of weathering of

rocks; so that the close of the accumulation finds the mass quite uniformly weathered on a vertical section. If, however, there should have been a long interval between the beginning and end of the aggregation, we shall find the above order reversed, and the freshest material on top. This last state of affairs can be met with in ordinary aggregation on a steep hillside, where the "creep" produced by rains or melting snows brings down the slope fragments recently riven by frosts to cover older deposits, and there will be a transition from a solid and fragmental top to a softer and more uniform bottom; but the rough, subangular outlines of the fragments in a "creep" aggregation cannot be mistaken for the glaciated rocks of a terminal moraine. An old terminal moraine would weather like any other accumulation of material; but on reaching its bottom we should not find the gradual transition to solid rock of similar character, and all the material of the lower layer would not be equally fresh. The study of these varying deposits will soon allow the observer to distinguish between them. According to the amount of movement in gathering the mass, we can distinguish:

1. **Débris in Place.** In this case there has been no movement; the rock has weathered above its own outcrop, and at a rate greater than that of denudation, so that accumulation has taken place. The results of such are:

(*a*) *Sands*, as in the case of quartzose rocks. These sand accumulations are of varying values, dependent on the purity of the mineral that composes them. Decomposed quartziferous *schists*, *gneisses*, etc., are frequently screened to furnish sand for building purposes. The Oriskany sandstone of eastern Pennyslvania furnishes abundant sands of a high character; the calciferous sand-rock of Chester County in the same State furnishes a milk-white sand; the Potsdam of New York, and the St. Peter's of the northern Mississippi

basin, also furnish on weathering sands excellent for glass-making.

Arkose (Brongniart) is a sandstone formed in place from the débris of granite, and is styled "granitic sandstone," as it contains quartz, feldspar, and mica in clastic grains, and solidified by pressure. It was originally noted in France, and is found on the borders of granitic masses. The Potsdam sandstone at South Bethlehem, Pa., rests against the hornblendic gneiss and granulite of the South Mountain, and its lowest layer shows (for a few inches) an abundance of feldspar.

(*b*) *Clays*, when argillaceous or feldspathic rocks weather. Granites form a sandy kaolin that can be levigated for pottery-making; argillaceous limestone loses its calcite and forms brick and terra-cotta clay—if quartzose or flinty, it furnishes a poorer article; slate rots to bluish or reddish clays which make good pressed brick; ferruginous bands in slates and shales are fired for "metallic" paint; the under-shales of the coal beds of the Appalachian area furnish excellent clay for fire-brick. Special varieties of clays have been thus named:

Bituminous Clay is the decomposed shales of the Trias and Tertiary coals of Europe. Of bluish—or blackish gray to black color; it smolders when fired, and burns red.

Saliferous Clay is from salt shales or marls, and contains much chloride of sodium, often in crystals, as in the Salina formation of the United States, and elsewhere in salt-formations.

Alum Clay is a decomposed "alum shale," and formed by the weathering of the shale and its pyritiferous content. It is common about coal outcrops that are "bony" and pyritiferous.

"*Mining*" is an earthy clay highly charged with carbon that forms when a coal-bed weathers. The name is a

miner's term. The same term is also used for any weathered soft clayey rock that can be readily worked with a pick underground.

Soft Ore is the miner's name for the leached limestone ore of the Clinton formation in the eastern United States. Atmospheric waters have removed the carbonate of lime, and left the iron as a mixture of carbonate, clay and limonite which is soft enough to be dug out with the fingers. It extends generally above water-level, and in some cases to one hundred feet below it, in the vicinity of Danville, Pa.

The secondary rocks formed from débris in place are numerous. All the primary rocks of any great development have their clays and earths formed from the weathering of their masses, and in this earthy or clayey matrix are held angular and rounded pebbles to form their breccias. These latter will be treated later under the head of "Megaclastic Aggregates," as there is very little difference, if any, in the appearance of a breccia formed in place, and inclosed in a matrix of its own rock, and the same when moved a short distance. The rocks forming in place are all characterized by a freedom from inclusions. In many cases the weathered tuff-conglomerates and breccias resemble the débris states of the same rock, as do the weathered tuffs the equally weathered débris; but the tuffs usually contain bombs, lapilli, and organic inclusions, especially if they have been aggregated by heavy rains or meltings of large snow masses, while the débris rocks fall over the outcrop and remain free from intermixtures with foreign substances. The following conditions of weathering have been given special names:

(*c*) *Laterite.* This term was originally given to the weathering in tropical lands of a primary rock to form a highly ferruginous clay that was soft when dug, but hardened on exposure to the air, and was used, like adobe, for brick-

making. The tropical climate induces a higher degree of oxidation than does the more northern and cooler one, so that all rocks in hot countries tend to form débris characterized by ferric rather than ferrous oxides. This has recently been noted in a comparison of the soils in the northern and southern States of the Union. The above term has been extended to include all weatherings in place attended by a high oxidation of the iron content and a further impregnation with the same, and we now have the terms sandstone-laterite, granite-laterite, tuff-laterite, etc., for the above conditions in these rocks. In Hungary trachyte-laterite is known by the local name *nyirock.*

(*d*) *Wacke.* This was formerly used to denote the weathered state of a rock poor in silica, and was afterwards extended to cover all weathered states of rocks by means of the adjective "wackenitic." In Europe this survives in "graywacke," but the term is obsolete here, and Dana expresses the state of opinion in saying in his last edition of the "Manual" "which used to be called *gray wacke.*"

2. Débris Slightly Moved. These accumulations are found on moderate slopes, and are usually of medium-sized fragments, more or less mixed with local foreign material of different origin, as:

(*a*) *Loam.* A mixture of clay and sand with more or less organic matter (humus) of a loose and earthy nature, and formed from the washings of higher lands through the action of rain or melting snow. In some countries the "black soil" is twenty feet deep, as India—less so in eastern Kansas and Nebraska.

(*b*) *Forest Soil.* Here the loam is mixed with stumps and limbs of trees, and accumulations of whatever animals inhabited or died in the region. The amount of humus is much greater than in loam, and the material more porous and irregular in size and character.

(*c*) *Dirt-bed.* A buried and "fossilized" forest soil, which is distinguished from the sedimentary beds with which it is intercalated by the absence of stratification and the remains of land animals only.

3. **Agglomerated Débris.** These accumulations are found at the bottom of high cliffs, near the bottom of steep slopes, and where the tops or sides of openings have fallen from weathering, or been crushed by the removal of their supports, as:

(*a*) *Cliff*-agglomerate, where the scaling of cliffs has heaped at their foot (either above or below water) an aggregate of material of all sizes, from the largest masses to the finest clay. The interstices are filled by subsequent rains and melting snows, so that the lower part is a "giant breccia." This is especially the case where the fall has taken place into water of considerable depth, and thus unaffected by wave action.

(*b*) *Slope*-agglomerate, where the material has slid down a steep slope gradually. Here the descent has been gradual, and the material is generally of smaller sizes and more uniformly compact.

(*c*) *Cave*-agglomerate, where rubbish has accumulated in a cavern by the gradual falling of the roof, and has been mixed with washings into the cavern, as well as cemented by whatever was held in solution by percolating waters. Under this German authorities name especially

Haselgebirge. In the salt region of the northern Alps, where agglomerates have been formed with a clay matrix by the caving in of caverns washed out of the rock salt.

(*d*) *Eruptive*-agglomerate, where large blocks have fallen into an old crater or on its slopes, and have been cemented by a new flow from the same crater or an adjacent one. In this case the cemented fragments are universally formed by the weathering of an old lava, and are not pyroclasts.

STRATIFIED AQUEOUS DEPOSITS.

These are accumulations which have been transported and sorted by water, and which are more or less homogeneous in composition. According to the size of the particles, they can be divided into:

1. Aggregates whose particles can be suspended in or pushed by water moving with slight rapidity, as a river after it leaves the piedmont portion of its course; or *microclastic.*

2. Aggregates whose particles are too large to be so suspended or moved; as *megaclastic.*

1. **Microclastic** Aggregates. These are loose or solid, and may be divided, according to the chemical composition of the materials into:

(*a*) *Argillaceous.*

(*b*) *Mixed.*

(*c*) *Quartzose.*

1*a*. *LOOSE ARGILLACEOUS AGGREGATES.*

CLAY.

A compound of kaolin (hydrated silicate of alumina) with silica, iron, lime, magnesia, potash, soda, and varying amounts of impurities, among which may be noted mica and partly decomposed feldspar. It is white when pure, but is colored in shades of yellow and red through brown to black. Pure kaolin and dry clay are not plastic, but generally fall to an impalpable powder; when moistened with water, it is more or less plastic; when fired, it becomes hard and stony; when dry and breathed upon, it gives a characteristic odor (whence the term "clayey" odor), and it adheres to the tongue.

Silica 40–90; Gr. 1.75–2; when heated at 100° C., 2.44–2.47.

These compounds are valuable on account of their plasticity, and this, as shown by Cook, depends on their fineness. After strong heating the combined water is driven off and the plasticity is lost, unless finely ground and allowed to stand with water. The color of clay is due to the impurities—chiefly iron in the form of protoxide, which is converted to the higher oxide by firing. Calcite neutralizes the coloring effect of iron, so that a marly clay will burn to a "cream" color instead of red. Sedimentary clays are found scattered throughout the world wherever deep water and gentle currents prevail. They can be told from glacial clays by their stratification, and the arrangement of their foreign burden in parallel lines and with the longer axes (if unequiaxial) parallel to the stratification. Glacial clays are generally more siliceous, and usually abound in foreign material of all sizes, and this is arranged haphazard, with no attempt at what has just been described. Clays joint on drying and become friable. A "fat" clay is tough and plastic, and with not much foreign matter; a "lean" clay is sandy, and therefore "loose" and with little plasticity. We can distinguish:

1. Kaolin (see under "Minerals as Rocks").

2. *Pipe*-clay, Plastic Clay. A white clay (therefore free from iron) of nearly pure kaolin.

3. *Brick*-clay, Tile-clay. An impure clay with a high percentage of iron (6–8 per cent) used for brick, tiling, terra-cotta. Clay with 90 per cent of silica has been used for making brick.

4. *Paint*-clay. The washings from limonite ores are now used for burning to make "metallic" paint. This is a highly ferruginous clay and is accumulated in settling ponds to which the wash-waters from limonite workings run. It also deposits from mine water.

5. *Fire*-clay, with little iron and but traces of the alkalies

and lime. When the impurities run above 4 per cent, it loses its refractory nature. Silica average 72.

6. *Fuller's-earth.* A somewhat greasy, earthy, and soft substance with greasy streak, with light shades of green and brown, that falls to mud on placing in water and is not plastic. It is found on the Rhine, in Belgium, Saxony, and England, usually as a formation in the Jurassic and Cretaceous; but in some cases it is the result of the weathering of gabbro-, hornblende-, and greenstone-schists.

1*b*. *LOOSE MIXED AGGREGATES.*

MUD.

An indefinite term applied to microclasts of varying composition when mixed with much water. In general it may be defined as an impure clay with abundant proportions of fine sand, and whatever material happens to be abundant at the place where it forms. It occurs at the surface of the earth after rain, behind dams, in the mouths of rivers that empty into sounds, and where the tide has little scouring effect, etc. When compact, it forms "mudstone."

In general, this compound has little claim for a place in lithology, but it has been found in the "Bad Lands" of South Dakota, filling dikes by injection from below, as in the case of igneous rock. This is shown by the unstratified state of the filling and the want of arrangement of unequiaxial particles relative to the dike-walls. A mixture of pure clay with much water is also called "mud," as is, in fact, any similar mixture of fine earthy materials. Under this can be placed:

1. *Alluvium.* The earthy, clayey deposit from flooded rivers upon low lands, which varies in size of grains with the velocity of the waters.

2. *Silt* is the same in origin, but mixed with the finer

material carried by low water and deposited on a small scale behind dams, and on a larger one in the mouths of rivers and over broad bays into which they empty. We speak of the "silting" of a river or bay, and refer to the filling of the muddy bottom, and the encroachment of the muddy shores. This is shown on a grand scale along the Atlantic coast of the United States, where the rivers empty behind sandy barriers and where there are broad sounds between the ocean and the land—from New Jersey to Georgia.

3. *Læss.* An earthy, clayey deposit (frequently calcareous, with marly nodules) forming unstratified layers in valleys, but, unlike alluvium, of wind-drift origin. This is included with aqueous deposits from its association with and its likeness to them.

4. *Adobe.* A similar deposit in the arid regions of the western States of the Union, consisting of calcareous clay mixed with angular quartz grains of great fineness, and folia of mica arranged haphazard. Of wind origin; unstratified, and used for the making of brick; hence the names "adobe" brick, "adobe" house. The winds from the Mojave Desert in California bring to the coast an abundance of this fine dust, so that the sun is almost obscured. Similar accumulations of wind and muddy wagon-wheels are seen in the buried cities of the East, old Rome being twenty feet below the present city level from this cause. The American "adobe" deposit is from 2000 to 3000 feet thick.

1c. *LOOSE QUARTZOSE AGGREGATES.*

SAND.

An aggregate of loose mineral grains (usually of quartz) varying in size from impalpable dust to an eighth of an inch. With the quartz are associated feldspar, mica, dolomite, calcite, magnetite, and (less frequently) other minerals.

This is the accumulation of the last states of the stable mineral components of rocks, and, though the accumulations are mainly due to water, a large number are due to wind, as in deserts and along sandy shores. The shape of the grains varies, but it can generally be said that the most angular grains are found nearest the origin of the sand, and that attrition and transportation round the edges rapidly, so that in studying the grains of sand of a peculiar nature from its origin to varying distances along a given line it was found that the greater the distance from the origin the more round the form. In general, it can be said that sands due to weathering and denudation of rocks by ordinary processes are by no means so sharp and angular as those due to glacial action; and in the case of fine sands and clays of glacial origin there is a decided glimmer to the cloud obtained by stirring in water that is absent in those of ordinary origin, unless they happen to be quite micaceous, and then the glimmer is pearly rather than vitreous. The following are some of the more important mineral varieties of sand:

1. *Magnetite*-sand. Found in rivers and along the coasts of regions where primary rocks exist. In many cases the sands are worked by magnetic separation for the magnetite.

2. *Gold-bearing* Sand. Found where rocks containing gold have weathered. California, Australia, the Urals, etc., are historical for the amounts of the precious metals thus found.

3. *Diamond*-sand. From Brazil, and formed of the débris of itacolumite. This contains also topaz, hyacinth, garnet, emerald.

4. *Tin*-sand is the débris of greisen, and is found most extensively formed at Banca and Billeton, in the Straits of Malacca, and less extensively in Cornwall and other tin-bearing regions, as the Dakota Black Hills.

5. *Crystal*-sand, where the original clastic grains have been built upon by quartz from solutions until a crystal outline has been formed by what Dana styles *crystallinic metamorphism.* This is occasionally found in loose sand, but the process usually compacts the mass into sandstone.

6. *Calcareous* Sand is formed on coral reefs and other calcareous formations, and is usually soaked in so strong a cementing material that, though it can be readily dug with a spade and cut into various shapes, it soon hardens to a solid and somewhat friable rock.

7. *Anthracite*-sand. For a short time after the wreck of one of the Philadelphia & Reading colliers north of Minot's Ledge, on the Massachusetts coast, the beach was lined with anthracite sand and gravel, but the wave action soon reduced it to impalpable powder and it disappeared. It furnished a good example of the "rolling" power of water.

8. *Pumice*-sand is found on the shores of the volcanic regions of south Italy, the Island of Teneriffe, the lake of Laach, and in other volcanic regions bordering on the water, where the waves can work over the débris and tuffs to form sand.

(*Blown* Sand bears to ordinary sand the same relation that lœss does to clay, as it is a wind accumulation, and found in deserts and along shores. These are sometimes called *Æolian* formations.)

SOLID MICROCLASTIC AGGREGATES.

These can be grouped under two general heads: those with predominant clay, and those with predominant quartz. The claystones and mudstones gradually shade into one another, and are distinct from the sandstones. These rocks have been cemented together by various media: pressure (with or without heat and moisture), solutions of various compounds—siliceous, calcareous, ferruginous, etc. They

may be of any color from white to black through yellows, reds, blues, and browns, less frequently greens, depending on the presence of iron, manganese, carbon, etc.

I. CLAYSTONE.

A compact and tolerably solid mass consisting of clay, not cleavable, and fracturing readily in any direction; variously colored.

This is the hardened sediment called "clay," and not the weathered aggregate of pyroclasts called "tuff." It is distinguished from the slates and shales by its want of regular fracture, as well as its inferior hardness and lower content of foreign admixtures.

II. SHALE, Argillaceous Shale.

A claystone which cleaves readily along its planes of stratification, but which shows no slaty cleavage. It is a consolidated clay or mud, and usually gray to black in color, with infrequent greenish, reddish, or purplish shades.

This is a softer rock than clay slate, owing to the absence of the pressure which in the latter produced cleavage. It frequently contains folia of mica, abundance of quartz sand, and other impurities that form the varieties named below. It shades into clay-slate in some localities, and into flagstone (by predominance of quartz). The varieties are:

1. *Schieferletten*, Rothelschiefer (Gümbel). This is a variegated shale with a greasy feel; easily fractured, and carrying a good deal of water, so that it is still somewhat plastic. It is an imperfectly solidified claystone.

2. *Bituminous* Shale, with a small amount of bitumen; of a dark-brown color. This will not burn by itself, and is thus distinguished from the "Brandschiefer," which will.

3. *Carbonic* Shale, with more or less carbon intimately mixed with it; of medium fine-grain; bedding-cleavage; shelly, splintery fracture across the cleavage; black color, and considerable percentage of iron, through the increase in which it shades into "black-band" ironstone. It occurs as "partings" in coal-beds, and burns fiercely in culm-banks, as its porosity furnishes sufficient air for combustion. When the "cut-off" was dug to isolate the fire in the Butler mine, near Pittston, Pa., the traces of a previous fire were found that had left the masses of the coal pillars intact, but had burned to ash the partings formed of coal shale throughout a large area, and on an average of eight to ten feet from the air.

4. *Micaceous* Shale. A sandy shale with abundant flakes of mica found in the coal measures.

5. *Alum*-shale. A pyritiferous shale associated with the coal, and wherever organic accumulations were sufficiently abundant to reduce the iron slimes in waters carrying sulphuric acid, by combining their oxygen with the organic carbon or hydrogen. It is usually dark-gray to black, and the pyrite is interlaminated with the clay or aggregated in masses from the size of peas to several feet in diameter. This is readily weathered to form alum-clay.

III. CLAY-SLATE.

A compact fissile claystone—usually colored dull blue or bright red (also purple, green, brown, and black)—with occasional admixtures of quartz and other minerals. The cleavage is quite perfect with respect to a plane which may or may not correspond to that of deposition, and may be produced by pressure, or by the arrangement of abundant unequiaxial minerals parallel to the plane of deposition.

Silica 40–75 (average 60); Gr. 2.5–2.85.

According to whether the cleavage is irregularly arranged with respect to the bedding plane, or generally follows it, we can arrange the above rocks into two general groups:

1. ARGILLITE, Clay-slate.

A rock with composition as above stated, but with few impurities, and with well-developed slaty-cleavage at any angle to the bedding plane.

This is the ordinary clay-slate, and is generally found in the older formations where beds of clay have been subjected to high pressures. In some cases, and generally in the harder slates, the pressure has destroyed the bedding-cleavage, but in the softer varieties it remains highly developed. In this rock there are few inclusions, and the hardness is due solely to pressure. The binding material is usually a small amount of carbonate of lime.

(*a*) *Roofing* Slate. This is dark-colored from carbon, or red from ferrite. It should be free from inclusions, from admixtures of pyrite and other efflorescent minerals, and from sand.

(*b*) *Ordinary* Clay-slate. A variety of the above without the high degree of cleavage necessary for roofing purposes, and with abundant inclusions of other minerals.

(*c*) *Pinsill*, Pencil Slate. This soft variety retains the bedding-cleavage, and breaks readily into long slender prisms used for slate-pencils (whence the Welsh name); also found in the Thuringian Forest.

(*d*) *Black Chalk.* A soft and highly carbonaceous clay slate used for marking purposes. Found associated with clay-slate in the Thuringian Forest, Spain, etc.

(*e*) *Carbonaceous* Clay-slate is a transition into the above and into alum shale.

(*f*) *Calcareous* Clay-slate, where the cementing medium is highly prominent, and forms nodules in the mass, as well as lighter bands.

The argillites are found in the regions of metamorphic rocks, and pass by regular gradations into the crystalline schists. In the United States roofing slates are found in Vermont and Pennsylvania. In the latter State they occur in the Hudson and Marcellus formations; mainly in the former.

2. PHYLLITE.

A clay-slate with abundant mica, a greater tendency to a crystalline texture, a greater luster, and a larger proportion of microcrysts uniformly scattered throughout the mass; with cleavage sometimes parallel to the bedding-planes, and due solely to sedimentation.

This variety includes two dissimilar types:

(*a*) *Micaceous* Clay-slate. A slate cleavable parallel to the bedding planes due to the pressure of the superincumbent mass and to an abundance of folia of mica arranged parallel to the bedding, as is shown by the intercalation of strata of grits and sands in the slate measures.

(*b*) *Phyllite* Proper. A highly crystalline slate; with perfect cleavage normal to the pressure (or inclined to it, see Becker's experiments); with a higher content of mica than that possessed by argillite, and much quartz, chlorite, feldspar, and rutile, and yet retaining the evidences of sedimentation, and not subjected to either regional or contact metamorphism, as far as the formation of "contact" minerals. The foreign minerals may have entered the mass as sediments from older rocks, or as crystallizations due to the pressure which produced cleavage. Argillite shades

into phyllite, and the latter may be taken as the intermediate state between argillite and argillaceous mica-schist. In general phyllite can be told from argillite by its higher luster. Many authorities class phyllite with the metamorphic schists on account of the content of crystalline minerals; but Geikie states that no line can be drawn between them, and Dana places them together.

SOLID QUARTZOSE MICROCLASTIC AGGREGATES.

SANDSTONE.

A rock composed of consolidated sand of any kind. According to the predominant mineral, we may have siliceous, granitic, micaceous, feldspathic, calcareous, etc., varieties.

Sandstones vary in regard to their cementing medium. It is generally siliceous or argillaceous; but, as in the Oriskany sandstone of eastern Pennsylvania, it is calcareous, and a short exposure to the weather causes the bands with this cement to crumble to sand. In many cases beach sands with a large content of shell fragments are more or less consolidated from the solution of the shells by meteoric water. Infiltrations of ferruginous solutions usually cement the lower layers of sand that rest against a non-porous medium with hydrated sesquioxide of iron, to form a ferruginous sandstone, in case the amount of iron is small; if large, a siliceous limonite is the result. As sandstones are sedimentary deposits, they are stratified; but the conditions of deposit may have been such as to permit one series of forces to act during a long period, so that the deposit for the period was uniform, and the layer of rock of great thickness. A succession of long and uniform intervals will produce a *thick-bedded* rock; of short periods, a *thin-bedded* rock; and of very short periods, a *laminated* rock. Sandstones, accord-

ing to the nature and strength of the cementing medium, are *compact*, *friable*, and *incoherent*. Some of the varieties are:

1. **Ferruginous** Sandstone, where the cementing medium is iron with a varying amount of clay. According to the form of this element we have:

(*a*) *Red* Sandstone, where the anhydrous oxide is present. Dana says that this form of oxide is due to the heated condition of the waters in which the sediments were deposited.

(*b*) *Yellow* Sandstone, where the hydrous oxide is present. Both of these are taken as evidence of scarcity of life in the area of deposition, or the organic aggregates would have been oxidized at the expense of the sesquioxides, and they would have been reduced to protoxides, and, as such, would not have colored the stone.

2. **Argillaceous** Sandstone is where the cement is clay, and this can be recognized by its odor, as stated under "Clay."

3. **Calcareous** Sandstone, where the cement is carbonate of lime, as in some bands of the Oriskany sandstone, noted above.

4. **Siliceous** Sandstone, where the cement is silica.

5. **Grit.** A sandstone where the grains are sharp and of the largest size (one-eighth of an inch).

6. **Flagstone.** A thin-bedded stone easily capable of being split parallel to the bedding, and furnishing large slabs for paving and flagging. This is sometimes called *laminated*, and some authorities state that the tendency is due to minute particles of mica. The slabs have evidently possessed an incipient tendency to separate in the mass, as their faces are frequently covered with dendritic markings, as are the joint faces of other rocks.

7. **Micaceous** Sandstone. A rock with much mica. The micaceous sandstones of the anthracite-coal measures of Pennsylvania carry a large mica content, as well as a large

percentage of carbon, and their tendency to split in thin laminæ is due to the mica, which shows readily in silvery folia against the black background. It is also called *fissile* sandstone. "Ganister" belongs here.

8. **Freestone.** This term is applied by quarrymen to any stone *that breaks equally well in all directions.* The "brownstones" used in facing buildings in the eastern United States are examples of this variety.

9. **Kaolin**-sandstone, with kaolin as a cementing medium. A rare stone, found in the Thuringian Forest, and from its refractory nature used for lining furnaces.

10. **Asphaltic** Sandstone, where asphalt is a cementing medium. Of limited occurrence in Europe.

11. **Crystal**-sandstone, where the grains have been furnished with crystal planes and terminations by crystallinic metamorphism. These occur in the older sandstones.

12. **Buhrstone.** A highly siliceous and cellular rock found in the Tertiary of Paris, and extensively worked for millstones. Also found in South Carolina.

13. **Dike**-sandstone. This is the unstratified filling of dikes in various rocks which have been filled in the usual way by injections from below, as the unequiaxial minerals are arranged haphazard without any relation to the dike-walls or the horizontal plane.

14. **Feldspathic** Sandstone is found near granitic outcrops. The lower portion of the Potsdam sandstone at South Bethlehem is somewhat feldspathic. A greater amount of this mineral would form *arkose.*

SAND-ROCK (Dana).

A rock made of sand of any kind, especially if not siliceous or granitic.

In this rock the predominant mineral is not quartz, but

a small amount of quartz may enter without placing the compound among the sandstones. As varieties are:

1. *Calcareous* Sand-rock is made of comminuted corals, shells, etc.

(*a*) *Coquina* (Spanish local name) is the shell rock of Florida, which is soft when excavated, but soon hardens, as seen in the old walls and buildings of St. Augustine, Fla.

2. *Glauconite* Sand-rock, when composed of grains of green earth and quartz.

3. (*Arkose* has already been noted on p. 261. It is a compound of feldspar, quartz, and varying amounts of mica, and is found at or near the outcrops of granite or gneiss.)

4. *Serpentine* Sand-rock is found on the Isle of Rhodes, as the result of the alteration and weathering of a basic volcanic rock.

MEGACLASTIC STRATIFIED DEPOSITS.

These deposits are composed of materials usually greater than $\frac{1}{8}$ inch, and are collected by flooded and torrential streams, and energetic wave action. The deposits are distinguished by the *shape* of their materials, and upon this shape depends the length of time during which they were being assembled and the name by which they are known, as:

Breccia.

Angular fragments of minerals or rocks firmly cemented together by some matrix or binding medium.

Brecciola (Brongniart).

A breccia composed of small fragments.

Conglomerate.

A rock composed of *rolled* pebbles or stones cemented in any manner.

Pudding-stone.

A conglomerate with *rounded* stones (Dana).

Gravel.

A loose and uncemented accumulation of rolled stones and *sand* of moderate sizes.

Shingle.

An accumulation similar to gravel, but of *larger stones* and *without sand.*

Hard-pan.

An accumulation of any of the above forms sufficiently cemented to break in masses, but readily broken up with the pick or bar.

The above rolled varieties are mainly of quartz, as no other mineral can last under the strong grinding induced by such powerful and long-continued forces. The breccias may be formed of any of the foregoing rocks. Conglomerates are consolidated shingles and gravels, and the latter are found where strong currents would sweep away the sands and roll the larger fragments. Breccias are found near the outcrops of the rocks from which they have been broken. The greater the distance of transportation the greater the loss of angular contour and the more the rounding, as well as the greater per cent of loss from abrasion, so that only the hardest rocks reach the accumulations of gravel and shingle, or remain there long, and the quartz rocks and siliceous porphyries alone resist the combination of grinding and weathering to which such aggregates are subjected. The classification of conglomerates and breccias has been abandoned by most authorities on the ground that both the material of the angular or rolled fragments and of the cementing matrix should be considered. The latter may be argillaceous, calcareous, ferruginous, or siliceous, and the fragments of any rock may be bound by any one of the above, or by a weathered portion of the same rock. These rocks will be distinguished from pyroclastic and oroclastic breccias and conglomerates by their cementing media. It

is proposed to classify all conglomerates and breccias, according to the cementing media and the material of which they are composed, as follows:

I. The cementing medium is of the same nature as the included fragments (either fresh or weathered) and formed by ordinary agencies. For such rocks the terms "quartz" conglomerate, "quartz" breccia, "trachyte" breccia, "porphyry" conglomerate, "slate" breccia, "limestone" conglomerate, will be used. These are *débris*-breccias and conglomerates.

II. The cementing medium is different from the inclosed fragments, and may be:

(*a*) *Siliceous.* A breccia with this matrix and trachyte fragments will be a "siliceous" trachyte breccia, etc.

(*b*) *Calcareous.* A conglomerate with this matrix and diabase fragments will be a "calcareous" diabase conglomerate.

(*c*) *Argillaceous.* This will furnish "argillaceous" limestone conglomerate, etc.

(*d*) *Ferruginous.* This will give "ferruginous" quartz conglomerate, etc.

GLACIAL AGGREGATES.

I. MEGACLASTIC.

There is but one group under this head where all the fragments are of large size, and that is of

ERRATICS, Perched Blocks.

Large masses of rock moved from their original position by a glacier, and left by its ablation scattered over mountain and valley along the line of its motion.

These are found abundantly over New England, and the upper tier of the middle and western-central States. In some places they are as large as a house, and are left, in many

cases, so delicately poised on top of other rocks (on which they are "perched") that they can be moved by the hand. They can be distinguished from the country-rock by their difference in composition. In the preceding pages notes have been made of the occurrence of varieties of rocks as "bowlders," "blocks," etc., of this origin.

II. **MIXED** Glacial Aggregates.

The majority of glacial deposits due to ice alone are found under this head; the distinguishing characteristic being a heterogeneous unstratified mixture of all sizes of material from the finest rock-meal to fragments as large as a house. This is generally termed *moraine-stuff*, and it can be separated according to its origin and mode of formation into:

1. *Lateral* Moraine-stuff. This was originally a "cliff" or "slope agglomerate" which had settled on the side of the moving glacier, and was transported with little or no abrasion; so that its particles are as angular as when they reached the ice. In the event of the stagnation and ablation of the ice this fringing string of material will rest along the flanks of the mountain or across the valley where the edge of the ice formerly existed, and it can only be told from local cliff- or slope-agglomerates by the finding of rocks moved out of place, as sandstone resting on granite, granite on limestone, uniformly red rocks resting on uniformly white ones, etc. In a valley its detection is easier. If, however, the material reached the ice-front, it became intermingled with the material brought in and under the ice. Two glacial affluents meeting in the central glacier would have their adjacent lateral moraines unite in a *medial* moraine, which, under similar circumstances, would be found along or across the valleys traversed by the ice, and parallel to the lateral moraines.

2. *Ground* Moraine. This material is formed under the glacier by the grinding effect of the rocks frozen into its lower portion on the surfaces traversed. The result is the grooving and polishing of both rocks and surface, and the formation of "rock-meal." The ablation of the ice leaves this as the lowest of the glacial formations, and on this falls whatever is carried in or on the ice. This is also called *subglacial* moraine. It usually has a cement of dense clay or rock-meal that incloses rounded and glaciated fragments torn from outcrops covered by the flow of the ice. In case the fragments are unequiaxial they are arranged with their longer axes parallel to the motion of the glacier. Like the lateral stuff, it is unstratified and quite compact from the pressure of the mass of ice. This is also called "bowlder clay."

3. *Terminal* Moraine. This is the heterogeneous material brought in any way by the glacier and heaped at its front. It contains all the material described above, and in some cases forms a hill more than 100 feet high and over a mile wide. For a description of the great terminal moraine of the Glacial period see the works of Lewis, Wright, Chamberlain, Salisbury, and others. (Kames, drumlins, etc., belong to geology, and not lithology.)

III. **MEDIUM** to **MICROCLASTIC** Glacial Aggregates.

These are caused by the ablation of the ice. It can melt under two general conditions: on a surface that will allow ready discharge of the water, or against a slope that will hold it in a body of varying dimensions; or, again, it can reach the sea or a lake, and "calve" its bergs upon the surface with their burden of material. The two last cases are practically the same, if we eliminate the distributing effect of tides; but with tides or currents the results are quite similar. We distinguish:

1. *Aprons*, where the ablation is above water, and where the water from the melting ice flows away with its burden down a slight slope. The large fragments remain at the ice-front; but the smaller are distributed in a succession of increments that produce stratification in case the flows vary, or an unstratified aggregate if they remain constant. This gradually thins out on going away from the ice-front, and passes from coarse to fine material, and finally dies out. The characteristic of this formation is the uniformity of the mass on a vertical section.

2. *Slack-water Clay*. This is formed by the discharge of the sub-glacial streams into a lake or quiet sea, so that the burden of fine rock-meal is distributed over the bottom, to form a deposit of extreme fineness at a distance from the front, but becoming more sandy and gravely near it. The bergs from the ice-front sail away with their burden of the varying kinds of moraine-stuff described, and, as they melt, they drop into the water their clay, sand, gravel, and bowlders. These in their descent arrange themselves so as to offer the least resistance to the water, and enter the clay at all angles; so that we can readily distinguish this formation from the "bowlder clay" or "till" by the want of arrangement of the burden, as well as by the looser state of aggregation, there being no ice-pressure to consolidate. The Packer clay of the Lehigh Valley, Pa., of this formation, and during the earliest of the ice advances, is in some cases fifteen feet thick.

PYROGENIC AGGREGATES.

(*A*) PYROCLASTS.

Fragments formed in any way during any portion of an eruption, and remaining loose or cemented by the eruptive magma.

These fragments may be taken from the country-rock in which the fissure was made, from the eruptive rock itself, or from any other eruptive rock. According to their state of aggregation, we can distinguish:

1. **Loose** Aggregates, where the fragments after ejection have fallen in loose masses and have not been cemented by any medium. According to their size, we find:

(*a*) *Blocks.* Large and generally solid masses (sometimes eight feet in diameter) ejected from volcanoes. Sometimes these are compact inside and slaggy outside, as if torn from the walls and partly fused; generally they are angular or subangular, and if round become bombs.

(*b*) *Bombs*, where the fragments are of considerable size, and have been somewhat fused and rounded before ejection, or during their ejection, from their plasticity and the rotatory motion to which they were subjected. Prominent among these are the "basaltic" bombs noted in the treatment of primary rocks, which consist almost wholly of olivine or a mixture in which it is predominant. Stelzner reports *obsidian* bombs from Australian volcanoes 1½ inches in diameter. Masses of slag as large as the head have been discharged from Vesuvius during an eruption.

(*c*) *Lapilli.* Fragments of slag as large as a walnut, and thence to minute sizes, and of various shapes. They are portions of the vesicular mass blown up by the force of eruption, and exhibit a vesicular structure within.

(*d*) *Ash*, Sand, when smaller than lapilli. It consists of the finest dust, as well as megascopic sizes, and (*m*) shows microliths, glass fragments, and minute crystals. The sand is coarser than the ash, and the series from coarse to fine would read: blocks, bombs, lapilli, sand, and ash. *Pozzulana* is a loosely coherent sand useful for hydraulic mortar.

2. **Pyroclastic Breccias,** Friction Breccias (in part). These can be divided according to the origin of the frag-

ments included, but the matrix in every case is eruptive. These breccias can be distinguished from ordinary ones by the matrix, as in the former the result of aqueous action is here replaced by that of fire. The breccias are named by stating both fragments and matrix, as before noted, with the exception that the fragments of a rock cemented by a matrix of the same are distinguished from the similar breccia formed by water by prefixing "pyroclastic" (see under (*b*), below). The varieties are:

(*a*) Where the country-rock is different from the eruptive magma. Here fragments of phyllite or sandstone cemented by eruptive basalt would be "phyllite-basalt" breccia, "sandstone-basalt" breccia. In the same way we would have "granite-quartz-porphyry" breccia, etc.

(*b*) Where the first outrush of the magma had its selvages chilled against the walls, and portions of these are torn off by the following rush and solidified with it. Here fragments and magma are alike, and we would have a "quartz-porphyry-quartz-porphyry" breccia, or, briefly, as stated above, a "pyroclastic quartz-porphyry" breccia, in distinction from a "quartz-porphyry" breccia formed from débris.

(*c*) Where the same or previous eruptions have formed a cone of vesicular lava, lapilli, etc., and subsequent extrusions have filled the crater and burst through the walls to form a breccia with the cinders, lapilli, etc. In this case the name would be as in the last, but the character of the breccia would be different, as the fragments would be more vesicular.

(*B*) TUFFS.

Aggregates of volcanic ejectamenta of varying size, more or less firmly compacted by the agency of water, and therefore more or less weathered.

These ejectamenta are the blocks, bombs, lapilli, sands, and ashes just described. On being thrown into the air they

fall at distances from the volcano dependent on the force and direction of discharge and the velocity of the wind, which sorts the material, and carries the particles to distances dependent on their fineness. The classic eruption of Krakatoa sent its fine dusts 50,000 feet into the air, so that they encircled the globe, and remained suspended long enough to produce the peculiar appearances at sunset during the following autumn. An examination of the deep-sea deposits shows us that volcanic ashes are distributed everywhere. This sorting causes a gradual transition from the coarse material at the foot of the volcano to the finest material at a distance, with a corresponding diminution in amount of sediment, and a corresponding increase in the proportion of foreign admixtures. The ejectamenta may fall under two general conditions: on land or into water. Falling on land they may accumulate as a dry, loose dust, or may become mixed with the condensed moisture that follows an eruption, and fall to the earth as a muddy rain, which will accumulate as a flow of mud that covers the low lands at the mountain foot, as was the case with Pompeii. The dry dusts remain until a heavy rain or the melting of deep snows forms with them a thin mud which flows in a similar manner, but, in this case, bears with it whatever may have accumulated on the surface during or since the deposit of the dust, such as portions of vegetation, etc. In either case these flows form regular strata and exhibit a "pseudo-fluidal" structure (the *migration* structure of Gümbel), and a section will exhibit compact, sandy, conglomerated, and brecciated states, with inclusions of foreign organic and inorganic material (leaves, stems, trunks, pebbles, etc.). In case the volcano be near a lake or the sea the ejectamenta will form a uniformly pure stratified deposit on and below the adjacent shore, and this will become intermixed with foreign sediment at greater distances, so as to form a gradual

transition from tuff to sediment, and both would inclose fossils of the period. Mügge proposes the term *tuffite* for *automorphic* tuff sediments, and *tuffoid* for similar regional *metamorphic* sediments (provided that it is regional and not contact metamorphism). Weathered tuffs resemble, when of fine grain, weathered débris in place, but a distinction can be made, as with tuffs foreign inclusions just noted, and bombs, lapilli, etc., are the rule; with débris in place, the exception. Laterites form from tuffs as from rock in place, and through the same causes. As tuffs are peculiar to volcanic rocks, their association with old eruptives, which are now known as intrusives, proves that they reached the surface, and that their surface deposits were similar to those of active volcanoes. Separating these into *tuff*, *tuffite*, and *tuffoid*, the following varieties have been noted:

I. TUFF.

Accumulations of volcanic ejectamenta on land, more or less solidified by rain and surface water.

(*a*) *Quartz-porphyry*-tuff, Porphyry-tuff, Felsite-tuff, Feldspathic Ash (Jukes). An earthy, clayey, and usually compact "claystone," colored from snow-white through shades of yellow and green to brown and bluish, and inclosing crystals of quartz and mica, and fragments of organic bodies. Silica 75–80; Gr. 2.62–3.02. Found in Alsace, Saxony, China, and abundantly in Wales. It passes over into the débris conglomerates and breccias of the rock.

(*b*) *Rhyolite*-tuff is abundant in Hungary and Nevada.

(*c*) *Rhyolite-perlite*-tuff is found with rhyolite-tuff.

(*d*) *Rhyolite-pumice*-tuff is extensively developed with rhyolitic extrusions.

(*e*) *Trachyte*-tuff occurs as a fine earthy mass of light colors in Hungary, Italy, and other trachyte regions, and

carries impressions of plants, etc., and as secondary products wood- and precious opal.

(*f*) *Trass* (Rhine), Pausilippo (Sicily), Tosca (Teneriffe), Moja (South America), are tuffs formed from mud-streams due to rain and melting snow, and contain a high content of foreign inclusions. They are all rhyolitic or trachytic in their composition, and are local names of the same formation.

(*g*) *Phonolite*-tuff is found in France, Bohemia, etc., near the phonolite extrusions, and *leucite*-phonolite-tuff occurs at the lake of Laach.

(*h*) *Andesite*-tuffs. From Santorin, the Andes, etc.

(*i*) *Mica-porphyrite*-tuff is reported from Italy.

(*j*) *Diorite*-tuff, or what seems to be such, is reported in one extended locality near Badmannsdorf.

(*k*) *Basalt*-tuff. This is a dirty gray to yellowish brown aggregate of small particles of basalt. It is full of the alteration products from basalt—green earth, calcite, zeolites, etc., and is extensively developed in basaltic regions.

(*l*) *Peperino* is an ash-gray tuff from the Alban Hills of Italy. The grayish matrix incloses folia of black mica, grains and phenocrysts of augite, leucite, and magnetite, with fresh and weathered olivine.

(*m*) *Palagonite*-tuff (v. Waltershausen). First noted at Palagonia, Sicily. It is a glassy basalt with much included water, and is caused by the action of hot water on the molten rock. Some authorities describe the rock as due to a discharge under water. It is compact and amorphous, with pitchy luster; color yellow to black; conchoidal to splintery fracture; H. 4.5; Gr. 2.4–2.6, and chemical composition of basalt. The action of the water has converted all the iron present as protoxide to sesquioxide. Rosenbusch has found that the interior of the palagonite fragments, which the original investigator named *siderome-*

lane, is a highly ferruginous and waterless tachylite. Palagonite is found extensively in Iceland, and with it *hyalomelane*-tuff.

(*n*) *Melaphyre*-tuff is reported from Germany and Greece.

(*o*) *Augite-porphyrite*-tuff is reported from the Tyrol and elsewhere.

(*p*) *Diabase*-tuff is extensively developed in the Voigtland, Harz, England, etc.; of gray to brownish green color.

All of the above rocks are characterized by the presence of inclusions that point to an origin on land. In 1861 v. Richthofen was the first to attempt to separate tuffs according to their manner of deposition and subsequent treatment; but Mügge, as stated above, was the first to propose names for the varieties formed under water and afterwards metamorphosed, as:

II. TUFFITE (Mügge).

A tuff that has accumulated under water and has inclusions of marine life, but which has been consolidated by pressure alone, and has not undergone "metamorphism."

Not very many types of this rock have, thus far, been reported, as the majority of observers have directed their attention elsewhere, and it is by no means the most easy matter to form the necessary distinction without the examination of a considerable area. Tuffites of quartz-porphyry are reported from Wales, of augite-porphyrite from the Tyrol, and the following rock is probably of this group:

Pietra Verde. This is found in Italy, southern Tyrol, the Balkans, etc. It is a rock like hornstone, with silica 50–69; Gr. 3; colored green to dark-green, and splintery fracture. It can just be scratched by steel, and is found among the Mesozoic sediments of the southern Alps.

III. **TUFFOID** (Mügge).

A tuff or tuffite altered by regional metamorphism.

This can only be told from the foregoing by the microscope in hand specimens; but in the field it will be found associated with metamorphic rather than sedimentary rocks. Under this seem to fall

(*a*) *Schalstein.* This is a metamorphosed diabase-tuffite, and is found extensively developed in Nassau, Devonshire, etc. Silica 17–44; Gr. 2.63–2.85. The base looks like a diabase-tuff; but it is mottled with greenish, gray, and spotted layers of calcite. It is sometimes amygdaloidal, and sometimes contains brecciated fragments of argillite and chlorite-schist.

(*b*) *Gabbro*-schalstein is reported from the upper island of Japan (Hokkaido).

IV. **SILICIFIED** Tuffs, Breccias, etc.

Tuffs, etc., with their original materials replaced by silica.

These are rare occurrences, and have thus far been reported from the Black Forest, Odenwald, in Europe; Saugus, Mass., where quartz-porphyries have been thus far found in this state, and in the Sudbury district of Canada in a band of silicified breccia more than forty miles wide.

OROCLASTIC (CATACLASTIC) BRECCIAS.

These rocks have been formed on immense scales by the crushing of rocks during orogenic movements. They can be divided into two general classes:

I. **SHEAR-ZONE** Breccias, Friction Breccias (in part).

Breccias produced by crushing of rocks along fractures, either directly or aided by a lateral movement, and cemented by the comminuted portions formed during the movement, and washed into the interstices; or by infiltration of aqueous solutions, either with or without metamorphism of a slight character produced by the heat developed during the shear.

In many cases, as along the shores of Avalanche Lake, N. Y., the rock of the shear-zone has been metamorphosed; but where the fragments retain their angularity, the class can be distinguished from other breccias, as follows:

From pyrogenous breccias of the walls of the country-rock by the nature of the matrix, which is eruptive in the latter and aqueous in the former.

From pyrogenous breccias of the tuff type by the differences in the included fragments.

From débris breccias by the greater angularity of the fragments.

From stratified breccias by the absence of sand and gravel and the general uniformity of the fragments.

II. **REGIONAL** Breccias.

Breccias produced by the crushing of extensive areas of the solid rocks during orogenic movements, with little or no displacement of the crushed portions, and a cementing by infiltration of aqueous solutions, and generally of a calcareous or siliceous nature.

These are found bordering the regions of mountain elevation. A good example is seen in the Siluro-Cambrian sandy limestone of eastern Pennsylvania, along the north flank of the South Mountain, as it exhibits large areas of rock crushed into fragments of all sizes, which have not moved from their places, and retain their lines of sedimentation, but which have

been firmly cemented by calcite infiltrations. The spaces between the fragments are usually thinner than a sheet of writing-paper, and the contrast between the various colors and textures of the limestone and its white cement is strong.

AUTOMORPHIC CHEMICAL AGGREGATES.

These are the results of the solution of minerals and their deposition by the drying or cooling of the liquid. The solvents are waters charged with various acids and of varying temperatures. The theories of the formation of these deposits belong to geology; the results can be grouped under two heads.

I. Aggregates from drying or oxidation.

II. Aggregates from cooling or saturation.

I. This class of deposits is by far the greater in number of species and extent of formations. The process has been going on since the beginning of the accumulation of water on the earth's surface. The materials held in solution are various; but the bulk of the deposits are found to belong to these groups.

1. Calcareous; 2. Haloidal; 3. Ferruginous; 4. Aqueous.

CALCAREOUS DEPOSITS.

These are mainly of two salts, the carbonates and the sulphates. Under the former are the limestones deposited during early times; but as these cannot be now told from highly metamorphosed later sediments, there will be no attempt to separate the two forms. The other form of limestone is shown in stalagmite and stalactite, formed at the present day wherever caverns exist. The sulphates are due to the drying of saline solutions and the deposit of the lime salts at an early period, as the solubility of gypsum is very slight.

(*a*) STALACTITE and STALAGMITE.

Stalactites are formations found on the roofs of caverns or other places composed of limestone, or containing limestone, as on the under sides of bridge-arches of limestone, or even of sandstone cemented with ordinary mortar. They resemble icicles, and are caused by the percolating water running preferably down certain spots with not too high velocity, The dropping water loses its carbonic acid and also dries, so that its soluble salts are added to the icicle-like form, and it increases in length till it sometimes, as in the Mammoth and other caves reaches many feet. The *stalagmite* is formed underneath the stalactite, where the drops have reached the floor, and is an icicle reversed, and growing upwards. The terms do not presuppose that the material is carbonate of lime, as stalagmites and stalactites are found in similar positions and formed of fluorite, barite, chalcedony, limonite, etc., and only the *form* of the deposit is indicated; but, as they are found of this composition many times more abundantly than of all the others combined, the terms without other limitations are usually referred to formations of lime. A section of either shows concentric rings, formed by distinct layers of material, which sometimes vary considerably in color.

(*b*) GYPSUM.

An aggregate of hydrous sulphate of lime; usually crystalline; sometimes compact or fibrous; white when pure, but gray, yellow, brown, and red when impure.

Gr. 2.32; H. 1.5–2.

Its softness, high content of water, and sulphur reaction distinguish it from similar-appearing rocks. The gray varieties are contaminated with bitumen, and the other colors are due to iron. As accessories occur pyrite, chalcopyrite,

quartz, mica, boracite, sphalerite, galena, halite, dolomite, sulphur, and other minerals to a less degree. *Alabaster* is a white, granular gypsum, sometimes semitranslucent.

(*c*) ANHYDRITE.

An aggregate of anhydrous sulphate of lime.

Gr. 2.8–3; H. 3–3.5.

This is told from calcite and dolomite by its failure to effervesce with acids, and from gypsum by its absence of water. It occurs with gypsum.

Both of these occur with beds of rock salt in lenticular masses. They occur to great thickness (600 feet) in the United States, and gypsum is mined in Michigan, Kansas, New York, Iowa, Virginia, Ohio, Utah, Colorado, California, Wyoming, South Dakota and Texas. From Utah come crystals of gypsum weighing hundreds of pounds. An alternation of light and dark layers of gypsum is called *tripestone.*

HALOIDAL AGGREGATES.

ROCK-SALT.

An aggregate of chloride of sodium; when pure, perfectly transparent and clear as water; variously colored by impurities; crystalline, fibrous, granular, foliated.

Gr. 2.1–2.2.

As a rock, salt is usually impure from gypsum, chlorides of lime and magnesia, clay, etc. The thickest beds of the world are at Stassfurt (1800 feet) and Sperenberg, near Berlin (3600 feet). In the United States rock-salt is found at the island of Petit Anse, La.; in the region of Wyoming, Genessee, and Livingston counties, N. Y.; and in Kansas, Nevada, Utah, and California. As salt-marls it is found in the Salina formation through New York, Ohio,

Indiana, Michigan, and western Ontario. The salt lakes of the United States are noted—especially the Great Salt Lake of Utah, which is 75 miles long by 40 wide. Other lakes occur in Utah, Nevada, California, and Texas with salt-formations in their vicinity.

CARNALLITE.

An aggregate of chloride of potassium and magnesium with conchoidal fracture and red color.

Gr. 1.6.

In a bed at Stassfurt 100 feet thick overlying the salt, and associated with it at other places.

FLUORITE, Fluor Spar.

A crystalline—rarely compact—aggregate of fluoride of calcium.

Gr. 3.1–3.2; H. 4.

This occurs in beds in a few cases; generally in veins in gneiss, mica-schist, clay-slate, both crystalline and uncrystalline limestones, and in sandstones. It is often the gangue of metallic ores. It occurs in Cumberland and Derbyshire, England, Saxony, Norway, and Baden. In the United States it is found in the adjacent counties of Pope and Harden in Illinois, and Livingston, Crittenden, and Caldwell, Ky., where it occurs as a vein associated with galena and other minerals.

CRYOLITE.

A coarse-grained and thick-bedded aggregate of the fluorides of sodium and aluminium.

Gr. 2.95; H. 2.5–3.

This occurs in a huge bed overlaid by granite at Ivigtût, Greenland, in snow-white masses partially transparent and

with vitreous luster. It is open-worked, and the opening in 1892 was 600 feet long and 200 feet wide and over 185 feet deep.

FERRUGINOUS AGGREGATES.

IRON ORES.

As the majority of these have been subjected to metamorphism, and all cannot be grouped under this head as far as origin is concerned, they will be treated under the head of "Minerals as Rocks." In this place it will be only noted that siderite is deposited as carbonate, and in many cases is intimately mixed with limestones and dolomites. The spots of iron soon become oxidized and are deposited as hydrated sesquioxide mud with other sediments, or accumulate in shallow ponds near the sea or lakes, and form lenticular masses of limonite. These by loss of water become hematite, or, by partial reduction through organic aggregates, become magnetic oxides. At any rate, the ores as a body are held to have an origin as given, and some authorities state that it is the sole origin. In the first part of this book (under "Gabbro") the ideas of other authorities were given that the primal source of the iron was through igneous injections and extrusions from abyssal sources.

AQUEOUS AGGREGATES.

ICE.

An aggregate of frozen (crystalline) water, granular, compact, schistose.

It may be formed by the solidification of the atmospheric moisture, as *snow*, and thence compressed to ice; or it may form on the surface of water immediately. We can distinguish:

(*a*) *Névé*, Oölitic Ice. A granular aggregate of ice formed on the tops of peaks, where there is a considerable

variation in temperature, by the rounding of the individual grains of crystalline snow and their gradual aggregation to form the oölitic grains of the *névé*, or *firn*, as it is called.

(*b*) *Glacier* Ice. A consolidated névé by compression and the infiltration of water, as the névé slides down the sides of the hills. The interior of the glacier ice is crystalline, in distinction from the granular character of the firn or névé. It is filled with air-bubbles when in small masses, and these may be full of mud. In large masses it is frequently an alternation of white layers full of vertical air-bubbles and blue, dense, and clear layers.

(*c*) *Water* Ice. Formed on the surface of water, and compact; white or greenish. It may be formed from fresh or salt water.

(*d*) *Ground* Ice. This is where shallow water freezes to the bottom, and thus incloses the stones and finer material of that bottom. It sometimes forms in deep water by the freezing of the lowest layer of water during very cold weather.

AUTOMORPHIC ORGANIC AGGREGATES.

I. ZOÖGENIC.

Aggregates produced by animal agency, and accumulated mechanically by any of the æolian or aqueous forces.

II. PHYTOGENIC.

Aggregates produced by vegetable agency, either grown in place or accumulated as above stated.

(*A*) *CALCAREOUS.*

1. LIMESTONE Group.

A compact uncrystalline aggregate of carbonate of lime; massive, concretionary, earthy, or hypocrystalline; colored white, whitish, grayish, bluish, blue, brownish, black; usually with accessory clay or sand, or both. Gr. 2.6–2.8; H. 3.

Here will be classed all forms of limestone, whether of chemical or organic origin, as already stated. Most limestones are of organic and zoögenic origin, though some are phytogenic. Chemical and zoögenic limestones will be noted together.

I. ZOÖGENIC SECTION.

(*a*) **LIMESTONE.**

A compact rock with conchoidal to splintery fracture; dull; color generally gray or yellowish blue, green, red, brown, or black.

It is rare that pure carbonate of lime is found in nature. The iron salts give the rocks red colors; carbonaceous impurities make them dark; clay and silica alter their hardness and change them from ordinary to hydraulic varieties. The ordinary limestones are compact, especially the recent geological ones; the older ones are frequently coarse-crystalline. It is often associated and mixed with magnesian limestone (dolomite), and in some cases the fossils will be dolomite and the inclosing rock calcite (Hunt). Limestone can be told from dolomite by its lower specific gravity, its greater effervescence with acids, and its action when powdered and heated on platinum foil (limestone powder heating quietly, glowing, and adhering together; dolomite powder swelling and becoming loose, or fusing to a slag if clayey). Many limestones appear to be compact rocks and non-fossiliferous on a fresh fracture, but on exposure to weathering the less soluble fossils remain (while the matrix decomposes), and thus obtain a high relief. Other limestones show at once their origin, and are almost entirely composed of fossils, which may be cemented by a compact matrix, or may be loosely held together by porous material washed into their interstices. Pure limestone contains 56 per cent

of lime. When metamorphosed, limestone becomes *marble* (q. v.). The inclusions in limestone are varied and numerous. The fossils are generally removed in the older rocks by infiltrations which have entirely replaced the body of the fossil, or have more or less fully filled the cavity with crystals of different minerals. As accessories are found commonly quartz, mica, pyrite, lead, sphalerite, chalcopyrite, and sulphur. These occur sometimes scattered through the mass, but usually in nests, strings, druses, geodes, etc., in the cavities, cracks, etc., in the rock. The fact that limestone was deposited as a calcareous mud in layers has allowed drying and consolidation to form joint planes normal to the bedding planes; and the further fact that it is readily soluble in water charged with carbonic acid has allowed its ready solution and etching by surface waters, which have thus hollowed it along joint and bedding planes, to form gashes and caverns of varying sizes, and in which the accessory minerals—especially the ores noted above—could be deposited. Its impregnation by solutions of magnesia has produced many dolomites, and solutions containing sulphuric acid have formed some gypsums and anhydrites. The varieties are:

Dolomitic Limestone. This is a porous yellowish to dark-gray stone with considerable carbonate of magnesia in its composition, but not enough to make a pure dolomite. Its specific gravity is higher than that of limestone in proportion to the amount of the dolomitic contamination. It is found associated with limestone, and in some quarries the infiltrating solution that has produced the dolomitization has proceeded irregularly downwards, so that portions of a stratum are limestone and other adjacent portions contain magnesia. In the Silurian limestones of Pennsylvania alternate layers in a quarry consist of pure and dolomitic limestone.

Siliceous Limestone. This may have the silica scattered throughout the mass to form a harder stone, or it may occur in nests, strings, etc. It sometimes occurs in nodules of chert or hornstone, that appear after slaking the lime, as lumps and sands. This variety is called *cherty* limestone. It is common in the Siluro-Cambrian limestones of eastern Pennsylvania, near the base of the measures.

Bituminous Limestone, Fetid Limestone, Swinestone, Stinkstone. This is generally dark-colored, and emits a bituminous odor when struck, heated, or rubbed. Some stones do not show this discoloration when fresh, as the limestone of northern Illinois, which is light-colored when quarried, but after exposure to air and dust becomes mottled with blackish patches. On treating with HCl a scum of bitumen is left. It belongs to the older geological formations, and is not found later than the Lias.

Argillaceous Limestone, Marly Limestone, Clayey Limestone. A usually gray rock with light-reddish and yellowish shades; of dull fracture—almost earthy; sometimes splintery; leaving considerable clay after treatment with HCl. Pyrite is abundant. These are transitions between limestone and marl, and are found on the borderlines between calcareous and argillaceous areas of sediments. In the great valley between the Kitatinny and South mountains in eastern Pennsylvania, the border between the slates of the north and the limestones of the south is occupied by a belt of argillaceous limestone, much of which is

Hydraulic Limestone. This contains from 10 to 50 per cent of silica, alumina, and iron oxide; does not slake at all under water, or at least very slowly, and its "setting" is due to a chemical combination of lime and magnesia with silica and alumina. It is always a transition between

a calcareous and an argillaceous formation, and partakes of the characteristics of both, being fine-grained, frequently cleavable, with greater tendency to splintery fracture (like shale), and with an effervescence to show its calcareous nature. It resembles the shales more than the limestones.

Lithographic Limestone is a slightly argillaceous and siliceous limestone, with an eminently uniform and fine grain; breaking with a subconchoidal fracture, and exhibiting, as a rule, a gray, drab, or yellowish color. It must be porous enough to absorb the greasy compound which holds the ink; soft enough to work under the engraver's tool, and homogeneous throughout; without veins, nests, cracks, or irregularities or impurities of any kind, so that the reagents will act on all parts with equal force. The best lithographic limestone is at Solenhofen, Bavaria; but stones are used from many other countries. In the United States it has been reported in Arizona, Alabama, Arkansas, Indiana, Illinois, Iowa, extensively in Kentucky, Missouri, Tennessee, Texas, Utah, and Virginia; but while small pieces may be found at these localities, the value of the stone is its possessing the above requirements, and its formation in masses of sufficient size. The Arizona stone seems to promise the largest and most uniform pieces.

Sandy Limestone is a transition between sandstone and limestone which, by weathering, leaves the sand in masses. This is common in the transition beds between the Potsdam sandstone and the Silurian limestone of Pennsylvania, and especially in Center County, where the weathering of the rock has left great depths of sand over the "sandy barrens." The fractured surface of this rock feels harsher than that of limestone, and the sand is left as a sediment on treating with HCl.

Ferruginous Limestone. A compound of ferric, or hydrated ferric, oxides and limestone. The iron gives red or brown shades to the rock, dependent on the amount. It is also sandy or clayey. It is not peculiar to any formation, and is found most commonly in the "marbles" of the United States.

Rotten Stone. A sandy and ferruginous limestone that has lost its lime from leaching, so that the ferruginous fine sand remains. It is used for polishing purposes. It is a porous rock, light, and found associated with sandy limestones. The loose calcareous mica-schists of Vermont are sometimes low in lime and mica and high in silica, and these weather to a coarse rotten-stone.

Glauconitic Limestone. A greenish limestone with abundant grains of glauconite. It is found in Europe in formations extending from the Trias to the Tertiary, in limited localities.

Slaty Limestone. This must not be confused with the argillaceous variety, which acquires a cleavage from the clay. In this case the slaty cleavage is due to pressure. It can only occur in fine sediments that have been strongly compressed, and is therefore rare. It occurs at Solenhofen, where the fine-grained rock cleaves so readily that it is used for slating purposes. It is sometimes associated with marble, and formed at the same time, but without the action that metamorphosed the latter.

Limestones may also be porous, nodular, geodic, cellular, fibrous, stylolitic, brecciated, conglomerated, and earthy; as well as characterized by the fossiliferous life from which they were formed by comminution of the remains, as nummulite, ostæa, hippurite, ammonite, encrinite, terebratula, muschelkalk, coral-rag, etc. In distinction from the compact forms just noted, these last, characterized by the varieties of animal life, are called *shell* limestones, *coralline*

limestones, *encrinal* limestones, as they are composed of the remains of mollusca, corals, or crinoids.

(*b*) CHALK.

An earthy limestone, rough to the feel, friable, white (sometimes gray and light shades of other colors), imparting its color to whatever it is rubbed against; of minutely fine and even grain, irregular fracture, and dull surface.

This is the result of an extensive aggregation of minute animal organisms in the form of oozes at the bottom of the deep seas, so that one million of them are required to form a cubic inch of the rock (Ehrenberg). It is usually pure carbonate of lime, but is frequently *marly*, and intermixed with the shells of larger animals that have dropped into it, as well as abounding in *flints*, which will be described later. In some localities on coral reefs the holothurioids and other animals that inhabit the reef form, by digesting the coralline fragments, a fine calcareous dust which solidifies, to make *coral* chalk.

II. PHYTOGENIC LIMESTONES.

(*c*) TRAVERTINE.

A somewhat cellular and concretionary limestone formed by calcareous waters flowing over a surface, mainly through the agency of conferva-like plants.

This is the method of origin of a good many travertines; though there are some due entirely to chemical action, as in the case of stalagmite and stalactite. Travertine is found wherever waters highly charged with carbonate of lime flow over the earth's surface, and sometimes in great masses, as at Tivoli, near Rome, and in this country about the lakes of the Great Basin. The hot springs of the Yellowstone Park

have been used as illustrations in all the standard geologies. The travertines can be divided into the *shelly* or loose sorts, which are almost entirely due to life, and the *compact* kinds, that are frequently of purely chemical origin. They are of light colors of red and usually yellow, and the dense kinds have a splintery fracture. St. Peter's at Rome is built of travertine. Under this rock come:

1. *Thinolite* (King). A crystalline travertine of unknown origin found in the Mono and Lahontan basins of the western United States. It is pseudomorphed after Gay-Lussite.

2. *Mexican Onyx.* This is a beautiful compact travertine in soft colors and clouded masses. H. 3.5; Gr. 2.75. This misnamed stone was first imported from Algiers; but the exhibit of the Mexican government at Philadelphia in 1876 called attention to the great extent of the stone in that country, so that in the United States it goes by the name at the head of the section. It occurs in bowlders of varying size from a few inches up to twelve feet in a tough reddish or dark-brown clay. In one instance (Antigua Salines) it is found in a hard flintlike country-rock that resembles "bastard jasper," in "veins varying from one inch to twelve inches in width" (Merrill).

(*d*) **TUFA**, Kalktuff.

A light, porous, cellular, earthy, friable limestone, formed by plant-life, and carrying an abundance of foreign inclusions, as leaves, sticks, moss, etc.

This is of the same nature as travertine, but of still more porous structure. In the Great Basin of the West it forms large masses.

(NOTE. The names "tuff," "tufa," are variously used by different authorities. They both designate a light, porous, friable aggregation, and some authorities use one word to designate all such, using the adjectives "volcanic" and

"calcareous" to distinguish the two general kinds. In this book the "tuffs" are volcanic, and the "tufas" organic).

(*e*) **OÖLITE,** Roestone.

A limestone composed of minute concretionary spherules from the size of millet-seed to that of a small pea, and resembling the roe of a fish (whence the name).

This rock was formerly thought to have been formed by concretionary action about grains of sand of any sort in waters charged with lime salts; but they are now thought to be the result of algæ. In the Great Salt Lake of Utah they are now forming as a scum along the shores, though no traces of lime are detected in the waters. It has been found that few of the waters of the earth's surface—no matter how high the temperature—are without minute forms of life, and to these is due the aggregation of various chemical compounds,—the groups above named, for instance,—and the similar siliceous ones that will be noted later. The grains of oölite are varying in structure: compact, radial-fibrous, concentric-crystalline, etc. Oölitic limestone is sometimes composed entirely of these grains, and sometimes they are sporadically scattered through an otherwise compact matrix. The limestones of Bath, Portland, Caen, etc., are good examples of this stone in Europe, and in England the Upper Jurassic is called "Oölite." A larger size of grain makes *pisolite*, or peastone, where the spherules are as large as peas, or larger. These are found in hot springs carrying a large proportion of soluble salts, as at Carlsbad, where the "sprudelstein" forms.

2. **DOLOMITE,** Magnesian Limestone.

A granular, compact, or earthy aggregate of dolomite (with more or less calcite); slightly effervescent with cold acid. Gr. 2.87–2.89; H. 3.5.

Pure dolomite or bitter-spar carries 54 per cent of car-

bonate of line, and the rest carbonate of magnesia. It usually varies by having a much greater proportion of lime, and containing a variety of ingredients similar to those in limestone. The differences between the two rocks have been given under "limestone"; in addition it can be stated that calcite slakes quickly, to form a "hot" lime, while dolomite slakes slowly, to form a "cold" lime. Many authorities hold that all dolomites are alterations in limestones through infiltrating solutions of magnesia. This may be the case, as we do not find travertine or tufa-formations in dolomite, but oölite is of both. In the Silurian of Pennsylvania alternating limestones and dolomites are found in the same quarry, and Hunt states that dolomite fossils are found in limestones, while v. Richthofen notes that the dolomites of the southern Tyrol are from reef-building corals. It is probable that many dolomites are due to the action of magnesia in solution and otherwise, while an equally large number were formed directly from the sea water by animal life, after the analogy of limestone. They occur in all of the older geological ages, and have many names that do not distinguish more than the fossils. As a rock it exhibits granular, compact, earthy, porous, cellular, brecciated, concretionary, and other forms. In the last the concretions are sometimes as large as cannon balls. It does not exhibit, or, at least, it exhibits very rarely, oölitic, slaty, fibrous, and stylolitic states.

3. MARL.

A compound of clay and calcite, or dolomite; compact, earthy, fissile, usually soft; crumbles on exposure to the air; effervesces with acids; hardness under 3.

The proportion of lime salts varies from 20 to 60 per cent. Beyond these on either side the rock does not crumble on exposure, and is either clay or one of the limestones. It is usually gray, but also yellow, brown, greenish, bluish,

violet, and red. It may be named after the geological formation in which it is found, from the fossils it carries, from its states or its impurities. Under the next to the last we have compact, earthy, and shaly marl; under the last calcareous, dolomitic, argillaceous, sandy, micaceous, bituminous, gypseous, glauconitic, shelly, and oölitic. The *copper-slate* of Mansfield is a bituminous marl carrying chalcopyrite.

(*B*) *SILICEOUS ORGANIC AGGREGATES.*

I. ZOÖGENIC SECTION.

1. **FLINT**, Feuerstein.

A gray to black, compact, and intimate mixture of amorphous and crystalline silica; hardness of quartz; fracture conchoidal; translucent on thin edges; occurs principally as nodules in the upper chalk of Europe, where it has been formed by organic agencies.

The first aggregates are the spiculæ of glass sponges, echini, and brachiopods. These on becoming triturated form aggregations into which siliceous solutions penetrate to consolidate them; or form around them by direct precipitation.

Chert, Phthanite, is an impure flint which consists sometimes of an aggregate of quartz and feldspar, and sometimes of silica alone. It is found especially, though not wholly, in limestones, where it has been formed by similar agencies, as shown by microscopic sections. It is also called *hornstone*, and much resembles felsite, but is distinguished by its infusibility. It is variously colored, and shows oölitic states. By a considerable admixture of iron it passes into jasper, and, with the addition of clay, to clay ironstone. In both the above the mixture of amorphous and crystalline silica can be detected by treatment with caustic potassa.

2. RADIOLARIAN OOZE.

A deep-sea deposit formed on the bottom of certain regions in the western and middle Pacific Ocean by minute animals that secrete silica—probably from the clay in suspension in those waters.

The deepest dredgings (five miles) show that the bottom of this ocean is covered with the skeletons of these animals, mixed with fragments of the spiculæ of sponges. Their size is as minute as in the oozes forming the chalk, already noted.

3. NOVACULITE, Whetstone.

A probable aggregation of calcareous ooze where silica has replaced the original calcite.

While some forms of whetstone are slaty from metamorphic action, and are highly siliceous argillites or phyllites, the novaculite of Arkansas is a microcrystalline aggregate of quartz sand; porous, and, according to Rutley, formed by replacement of calcite by silica, as the structure (*m*) is like flint. The Arkansas variety is snow-white, with conchoidal fracture, and the hardness of quartz. The *whet-slates* of Europe are either siliceous phyllites of whitish to greenish color (in some localities owing its value to minute crystals of manganese garnet, of which it carries a predominant portion of its bulk), or they are siliceous argillites. They occur in Wales, Devonshire, the Thuringian Forest, etc., but in none of these localities do they resemble the novaculite of Arkansas. A coarser oil-stone is found in Orange County, Ind.

II. PHYTOGENIC SECTION.

1. DIATOM-EARTH, Infusorial Earth.

An aggregate of the skeletons of the microscopic plants called diatoms; whitish, yellowish, light-brown.

This is forming now in the south Pacific Ocean at great depths. It occurs in beds near Bilin, Bohemia, where Ehrenberg estimated that 41,000,000,000 of skeletons existed in one cubic inch. It is also found near Richmond, Va., Monterey, Cal., Yellowstone Park, etc. As varieties are:

(*a*) *Tripoli*, Polishing Slate. This is a soft rock easily pulverized, and with slaty structure, formed of diatom earth. It is extensively used for polishing purposes, and is divided in Bohemia into two varieties—*polirschiefer*, soft, friable, not adhering to the tongue, and *saugschiefer*, more solid (from opalizing), and adherent to the tongue. It is found in Nevada.

(*b*) *Kieselguhr*, Infusorial Meal, Diatom Mud (Naumann). This is a finer grained aggregate than the last, and is used as the "dope" for dynamite. It formed great deposits in the Tertiary period, and is found from Chesapeake Bay to Richmond, Va.; also in Nevada, California, Oregon, and Utah. *Randanite* is the same rock from Algiers and France, as named by Salvétat.

2. FIORITE, Geyserite, Siliceous Sinter.

An aggregation of opal silica through the action of conferva-like algæ.

At one time the formation of sinter was thought to be due to the drying of the solution; at another, to its cooling. Through the researches of W. H. Weed it is found that the aggregation is due to a plant that grows an inch in about ten weeks and secretes silica. The deposits are beautifully exhibited on a grand scale in the Yellowstone Park. The rock is of two kinds—*sinter*, compact and hard; *siliceous tufa*, less compact. It also forms stalactites on the edges of the basins; spheres and other forms under the escaping waters;

covers leaves and twigs with incrustations, etc. The color is usually snow-white, also yellowish, grayish, reddish, and bluish, according to the impurities contained. The surface of the deposit is wrinkled, smoothly irregular, etc. The mass is cheesy when first formed, but hardens on exposure to the air. It is found with geysers and silicated springs in Iceland, New Zealand, in great profusion, and as above stated, in the Yellowstone Park.

(C) *PHOSPHATIC ORGANIC AGGREGATES.*

The chief source of organic phosphates is zoögenic, as the amount of phosphoric acid secreted in plants is inconsiderable, and its aggregation is under conditions that destroy all traces of its origin. Plants are an ultimate source of the element, as they furnish food for animals, and thus permit the concentration of phosphorus in their bones and excrements, shells, integuments, etc. These during all geological time have been triturated and buried under conditions favoring the formation of concretions of phosphoric acid with lime and clay, so that from the beginning of animal life on the earth to the present day there have been aggregations of phosphates as impregnated sediments, as nodules, as fresh or fossilized remains, and as excrements. We can distinguish:

1. PHOSPHORITE (Kirwan).

An aggregate of phosphate of lime; compact; whitish, yellowish, grayish, or brownish.

Gr. 3–3.2; H. 5 and less.

The "phosphorite" of Kirwan, which included all apatites, has been extended to include all compact aggregates of phosphoric acid of any origin. They occur as uniformly disseminated sediments, as nodules in various cements, and

as metamorphosed crystalline aggregates. Here will be treated "apatite," though its origin may be inorganic.

(*a*) *Apatite.* A crystalline, cleavable, granular-massive aggregate of phosphate of lime with either chloride or fluoride of lime. H. (crystal) 5, (massive) 4.5; Gr. 2.92–3.25. Luster vitreous–subresinous; streak white; color sea-green, bluish green, violet-blue, sometimes white, occasionally yellow, gray, red, brown—usually dull colors; transparent to opaque; brittle. It occurs most extensively in metamorphic rocks of all ages, and especially in metamorphic limestone. It occurs massive in large veins in limestone of the Laurentian near Ottawa, Perth, and Kingston, Canada, where it is mined for fertilizing purposes. A massive, impure, altered apatite, earthy, whitish to grayish color, and resembling lithographic stone, is called *osteolite*, as its composition is the same as that of bone. It is found in fissures and cavities in dolerite, etc., in Bohemia, the Fichtelgebirge, etc.

(*b*) *Phosphate Rock.* An aggregate of phosphate of lime, with calcite, clay, and other impurities, occurring in beds, and enclosing fragments of shells, bones, etc., in small amounts. It occurs in *beds* in the Bala limestones of Wales, in the Jurassic of Bavaria, and elsewhere in Europe, and in the Devonian of Tennessee under the Chattanooga shale. The last is bluish black, yellowish, light-gray, full of nodules, shell impressions, and in some cases resembling air-dried *coquina.* It also occurs in South Carolina and Florida.

(*c*) *Phosphatic Chalk.* A series of brownish layers in the chalk of Belgium, France, and England where there is a concentration of phosphate, which has replaced the shells of foraminifera. The proportion of phosphate of lime runs as high as 45 per cent.

(*d*) *Pebble Phosphate.* This is a concretionary aggregate extensively developed from South Carolina to Florida as

pebbles of varying sizes imbedded in limestone, clay, or sand. The limestone is white and phosphatic; the clay is marly, and contains, with the nodules, the teeth of sharks and bones of animals, land and marine. The concretions are called by the miners "hard rock," the inclosing limestone "soft rock"; "land pebble" is the concretional deposit on land, but when the rock weathers and the concretions are washed into the rivers with sand and clay, the aggregation is called "river pebble." It contains about 26 to 34 per cent of phosphoric acid, and is found near the surface in the river beds, and in Florida under a thin covering in the swamps, and is recovered by dredging. The land deposits are mined and treated by washing.

2. BONE-BRECCIA.

An aggregate of fragmentary bones of extinct or living animals, more or less mixed with earth, sand, or lime.

The "breccia" refers to the fragmentary state of the bones. This is formed on the floors of limestone caverns, either through their having been used as dens by animals, or through the accumulation of bones and other rubbish by streams flowing through the caves or by floods. The dropping waters from the roof furnished lime as an admixture—in case the cave was continually inhabited—for the accumulations, or, in the event of its remaining vacant for long periods, covered the accumulations with a layer of stalagmite. In a slight degree the *cave earths* formed by the accumulations in caves through human habitation can be classed here. They will be distinguished by the admixture of charcoal, portions of weapons and utensils, and other indications of human residence. As caves are favorite habitations for bats, their bones are found in the loose calcareous tufas forming in caves of the present period in America.

3. BONE-BEDS.

Aggregates of the bones of land and marine animals in the older geological formations.

This is a geological term for the limestone beds of the Rhætic formation in Swabia, Franconia, Thuringia, etc., and in England geologists note the "Lias bone-bed" and the "Ludlow bone-bed." These beds are largely made up of the bones of animals. The South Carolina and Florida beds are also called "bone-beds."

4. COPROLITE-BEDS.

Aggregates of the fossilized excrement of vertebrated animals.

These begin in the Carboniferous formation, with the aggregates of fossil excrement of ganoids, with their scales and bones. The beds become more important as we go higher, and in the Cretaceous they are worked for manure. These beds are noted especially in England and Europe. Logan reports a possible occurrence in the Lower Silurian of Canada.

5. GUANO.

An aggregate of the excrement of sea-fowl formed on islands in the rainless tracts off the western shores of South America and Africa.

This is an earthy, white, gray, or yellowish brown accumulation of unpleasant odor. The absence of erosive agents allows the accumulation to reach over 100 feet in many cases, and with it are found inclusions of animal and vegetable life. The islands are the roosts of sea-fowl, and where they form their nests.

(*D*) CARBONIC ORGANIC AGGREGATES.

These are all vegetable aggregates, and have generally grown in place, but in some cases have accumulated through other influences. They can be divided into rocks forming a regular series from plant to mineral. All are combustible, black or brown, and can be divided as follows:

Peat, or vegetable matter that has undergone little alteration.

Lignite, Brown Coal, containing much bitumen.

Coal, Soft Coal, Stone Coal, containing much less bitumen.

Anthracite, containing little or no bitumen.

Graphite, without bitumen, and only combustible under the blowpipe.

Semibituminous coal and semianthracite are transitions between bituminous coal and anthracite, and meta-anthracite is a transition between that rock and graphite.

In examining the geological record we find that the recent formations are of peat, and the oldest are of graphite. The peats have undergone little consolidating pressure — the graphites have been highly metamorphosed.

I. PEAT, Turf.

A yellow, brown, or black aggregation of vegetable matter, varying from light and fibrous interwoven states to compact and clayey ones.

This is a more or less decomposed and chemically altered accumulation of vegetation, dependent on its position in the mass and the age of the same. In old peat bogs that have been undisturbed there is a gradual transition from the light-yellowish or brownish yellow fibrous aggregate of growing moss, through the dead and brown fibrous aggregate slightly below the surface; the still lower and more compact mass

with brownish fibers and generally blackish color; the lower black and still more compact mass with few shreds of fibers, to the compact and creamlike black mass that may be more or less earthy or clayey, from admixtures of sand or clay. The preglacial beds are covered with gravels, and compressed into compact and cheesy masses that are compressible with the fingers when fresh, but fracture with a pitchy luster when suddenly strained, and dry to a hard mass with strong luster. The ordinary peats resemble, when perfectly decomposed, black clays when wet, and varieties of brown coal when dry. Peat can be divided according to the plants from which it was formed, as moss-peat, heath-, grass-, leaf-peat, etc. The states near the bottom of the beds are called mud-peat and pitch-peat, according to their state of aggregation, while paper-peat has been compressed strongly enough to cleave readily. As accessories are found limonite, infusorial earth, gypsum, pyrite, and vivianite. The weathering of pyrite forms an iron vitriol, and makes the variety *vitriol*-peat. Peat burns with a strong pyroligneous odor, and gives a brown coloration when boiled with caustic potassa, from the presence of cellulose. When subjected to a pressure of 6000 atmospheres, peat entirely loses its organic structure, and forms a coal-like mass with brilliant luster, black color, and great brittleness.

II, LIGNITE, Brown Coal.

A brown or black earthy mass, with brown streak, highly inflammable, compact or earthy.

This is a partially altered vegetable aggregate, compressed strongly. It shows traces of vegetation at times, such as stems with woody fiber, etc. Its specific gravity varies from 0.5 to 1.5, and its carbon content from 55 to 75 per cent. As accessories are found amber, asphalt, gypsum, calcite, pyrite, sphærosiderite, and numerous organic compounds.

This differs from "soft" coal by its greater content of bitumen, by its pyroligneous odor and its brown coloration of boiling caustic potassa, as well as by its lower specific gravity and hardness. As varieties are:

(*a*) *Pitch* Coal. A brown coal with pitchy or waxy luster; black, compact, and exhibiting the greatest hardness of all the varieties; without traces of woody structure; of the highest density and carbon content of the lignites. It occurs in Bavaria.

(*b*) *Dysodile*, Leaf Coal, Paper Coal. Yellowish brown, saddle-colored laminæ of the thinness of paper from compression, or the presence of numerous leaves from which it was formed. It carries bitumen, infusorial earth, and clay. It occurs near Bonn and elsewhere.

(*c*) *Moor* Coal is a feltlike aggregate resembling turf.

(*d*) *Bituminous Wood* retains the texture of the wood from which it was formed.

(*e*) *Pyropissite* (Kengott), Wax Coal, forms the upper bench (3½ feet) of certain brown coals in Saxony. It is a dark grayish yellow to yellowish brown plastic mass, with greasy, smirchy character; easily breaking with earthy fracture; lustrous streak; Gr. 0.9; lights in the flame of a candle and burns with a clear flame (giving off much steam), and forms a black pitchy mass.

(*f*) *Needle Coal*, from Alsace and elsewhere, is an aggregate of acicular elastic blackish-brown particles with greasy luster on fracture. The "needles" are often over seven inches long.

(The Tertiary lignites of Brandon, Vt., have long been noted for their vegetable remains and especially the fossil fruits. Brown coal is found generally in the Tertiary, and is a transition between peat and coal.)

III. **COAL,** Soft Coal, Stone Coal, Pit Coal, Bituminous Coal.

A compact mass, usually brittle, sometimes with distinct jointing or cubical cleavage, sometimes with conchoidal fracture; colored shades of black; streak grayish black to brown; burns less readily than brown coal, but gives a clear flame; no pyroligneous odor, but strong bituminous smell; usually friable. Gr. 1.2–1.35.

This is distinguished from brown coal by its smell and its failure to afford a brown color when boiled with caustic potassa. It contains less bitumen than brown coal, but shows in many places aggregates of a charcoal-like substance retaining the texture of wood, and called by the miners "mother of coal." It contains from 75 to 90 per cent of carbon, and carries as accessories pyrite and marcasite (which are seldom absent, and give the red and pink colors to the ash), pyrophyllite as linings of the joints, and others sporadically distributed. This is found extensively developed throughout the world, and especially in the Appalachian coal-field that stretches from Pennsylvania to Alabama and Ohio, and in large areas, elsewhere noted, in the United States. It has the following varieties:

(*a*) *Caking* Coal, where the mass (whether solid or in powder) fuses and runs together in the fire to form *coke.*

(*b*) *Splint* Coal, Hard Coal, Non-caking Coal, breaks with conchoidal fracture and in large masses; is not friable, nor so easily inflamed as the caking coal, but leaves a loose ash. It adheres while burning, but does not leave a strong coke, nor does it fuse together.

(*c*) *Cherry* Coal, Soft Coal, Sand Coal, is a softer coal than the last, and when powdered and inflamed its grains

burn separately and do not coalesce. It has a high resinous luster, is easily friable, and readily inflames.

The first two form the *gas* coals, as they are extensively used for its production, and are found abundantly in the Appalachian coal-field. This form of coal can still further be divided, according to texture or other variations, as follows:

1. *Cannel* Coal, Candle Coal, Parrot Coal. This is a dull coal—at times appearing like black claystone—that burns with a clear flame like a candle. In Scotland it is called "parrot," from the chattering noise caused by its cracking when inflamed. It breaks with a shaly to even fracture. The more lustrous varieties leave little ash, the duller ones a larger amount. This is found in Ohio.

2. *Torbanite*, Bog-head Coal, was a formation (now exhausted) in Scotland that carried a large amount of ash and of volatile matter, and was extensively used for gas-making.

3. *Jet* is a black variety of brown coal, compact, appearing like asphalt, taking a high polish, readily cut and worked, and extensively used for jewelry and ornament. It occurs in small isolated masses in formations later than the Carbonic in Franconia, France, Yorkshire, etc.

IV. SEMIBITUMINOUS Coal.

A coal of general appearance like the last, but differing in chemical composition and density.

It varies from 1.3 to 1.45 in Gr., and has but 12 to 20 per cent of volatile constituents; while bituminous coal has Gr. 1.2–1.35, as above given, and carries more than 20 per cent of volatile matter. Both of these coals smoke when burning, especially at the beginning of the inflammation, and in this respect differ from anthracite, which burns without smoke or smell. This coal is a transition between the

bituminous and semianthracite coals. In Virginia and North Carolina.

V. SEMIANTHRACITE.

A coal with but 6 to 11 per cent of volatile matter, and with Gr. 1.4–1.5; luster dull, angular fracture, and hardness less than anthracite. In Pennsylvania, Arkansas, etc.

VI. ANTHRACITE (v. Haidinger).

An iron-black to velvet-black coal with vitreo-metallic luster; hard and brittle; Gr. 1.5–1.7; conchoidal fracture; volatile matter under 5 per cent.

This coal is "hard" anthracite, in distinction from the semianthracite. It burns with a short flame, does not easily inflame, and gives no smoke. It is found in south Wales with semianthracites; but the greatest development is in the Carbonic of Pennsylvania, where it covers large areas, and is worked in fourteen named beds, and many "leaders" of varying thinness. The "anthracites" usually mentioned in other countries are more of the semianthracite type. There is no general distinction for this coal, as it varies in appearance in each bed, and in the same bed in different districts, and even in the same mine. The "Mammoth," "Baltimore," "Jugular," or other names for the (E) or largest bed of the measures, generally maintains an average thickness of 8 yards, and sometimes reaches 38 yards. It has a high luster, and the middle "benches" break with a conchoidal fracture, but the upper bench will frequently exhibit as high a degree of cubical cleavage as in caking coal. The (B) bed, which lies upon the Pottsville conglomerate, sometimes is a bed 8 yards thick (Nanticoke), with high luster and no partings of slate; twenty miles to the north it is a 4-yard bed so entirely without luster that its

shipment with other coals has condemned the mixture as "slaty." In this respect it resembles cannel coal in having a high per cent of ash. The principal accessories are pyrite, marcasite, and pyrophyllite, and the presence or absence of the pyrites grades the coals as red or white ash, the former burning to a free ash, the latter to a slaggy mass. The bottom clay of the (F) bed is frequently a "black-band ironstone."

VII. **META**-anthracite.

A metamorphosed anthracite occurring in regions of orogenic movements; Gr. 1.8–1.9; luster higher and hardness greater than in anthracite.

This occurs in the Rhode Island (Carbonic) coal-field and is found in regions of greatest disturbance. The coal has become partially turned to graphite and will only burn with forced draught. All of the Rhode Island coal is harder and denser than that of Pennsylvania, as it has undergone a certain amount of metamorphism.

VIII. **GRAPHITE**, Black Lead.

A grayish black aggregate of nearly pure carbon; flaky to granular and compact; soft, with greasy feel; inflammable under the blowpipe; with metallic luster; black streak (like lead pencil). Gr. 1.9–2.2.

This occurs entirely in metamorphic rocks. As accessories are silica, clay, oxide of iron, hornblende, mica, apatite, pyrite, rutile, corundum, etc. It is found in Siberia, Bohemia, Austria, etc., and in the United States along the Archæan area from New York to Alabama, and in the same area in Massachusetts and Michigan. The principal place is near Ticonderoga, N. Y., where it occurs in a graphite schist, containing 8 to 15 per cent of graphite. It is also worked at Cranston, R. I., in connection with the meta-

anthracite coal just mentioned. In the Rocky Mountains graphite beds occur in Albany County, Wyo., Gunnison County, Col. (where it forms beds two feet thick, and very impure), Humboldt County, Nev., Beaver County, Utah, and in the Black Hills of South Dakota. Graphite schist is metamorphic, but it is closely connected with the foregoing, and as it is sometimes found with phyllites, it can be placed with them.

(*E*) *HYDROCARBONIC ORGANIC AGGREGATES.*

I. **ASPHALT,** Mineral Pitch.

A brownish black to black amorphous opaque mass; strongly smelling of petroleum; when cold, smooth, brittle, resinous luster and conchoidal fracture; melts at 90° to 100° C., and burns with a bright flame, with bituminous odor and much smoke; plastic at ordinary (summer) temperatures; Gr. 1–1.68; streak paler than the fractured surface.

It occurs associated with petroleum as its hardened form, as impregnations in rocks (already noted under limestones, sandstones, marls, etc.), and as independent beds. At Seyssel, France, it forms a large deposit, but the most important deposit in the world is the asphalt lake of the island of Trinidad, 1½ miles in circumference. It also exudes from the ground on the borders of the Dead Sea and in Sicily. In the United States liquid asphalt is found in Ventura County, Cal. An exceptionally pure form is found near Fort Duchesne, in the Uintah Reservation of Utah, under the name of *gilsonite* or *uintaite*, which is used almost entirely for varnish. Bituminous sandstones are found in California, Colorado, Kentucky, Utah, and limestones in the last State and Texas. The liquid bitumen is full of vegetable remains; and also carries varying propor-

tions of earthy contaminations. It is extensively used for paving and forming the matrix for bricks formed of limestone breccia.

II. OZOKERITE, Mineral Wax.

A white (when pure), leek-green, yellow, brownish yellow, or brown amorphous mass; translucent; greasy; melts at 56° to 100° C.; Gr. 0.85–0.95; ordinarily it is soft and plastic and with fibrous fracture. The greenish shades are due to dichroism.

Its name refers to its waxlike appearance and its foul odor, but some varieties are odorless. It occurs principally in Galicia in Austria-Hungary, and in the United States near Thistle, Utah. The European product is valued at from $800,000 to $1,000,000 per annum. Occurs with bituminous clay, coal, etc.

III. PETROLEUM, Mineral Oil, Kerosene.

A thick to thin fluid; colorless, yellow, or brown; translucent to transparent. Gr. 0.7–0.9.

It occurs in rocks of all ages from the Lower Silurian to the present epoch; most commonly with argillaceous shales and sandstones, but sometimes with limestones. It is found along the western shores of the Caspian Sea, in Italy, Sicily, in mid-Europe, at Rangoon, Birmah, and in the United States in New York, Pennsylvania (especially), Ohio, Indiana, Virginia, Kentucky, Illinois, Colorado, and California. Oil, gas, and salt water are found together in the wells, and when first struck the oil is forced out to great heights by the pressure within, and flows for varying lengths of time till the pressure is exhausted. At the present time the old fields are becoming exhausted.

IV. BITUMINOUS SHALE, Oil Shale, Brandschiefer.

Shale containing sufficient oil to allow economic distillation; pitch-black to brownish black; affording sometimes a greasy streak; burning in the fire with a bluish flame when lit with a match.

These shales are filled at times with the remains of fish, and thus show the origin of the oil. They probably represent the shales from which the petroleum now flows, and when that shall have lost its ability to flow the reservoirs will resemble the above shales. These are extensively mined for distillation, though by no means so extensively as before the discovery of petroleum, but after its exhaustion their value will return again. They are found in Scotland, Germany, and in the United States, as stated under "Asphalt," especially in California, Colorado, Kentucky, and Utah.

(*F*) *FERRUGINOUS ORGANIC AGGREGATES.*

NOTE.—Microscopic examination shows that many limonites and sphærosiderites are aggregated by diatoms and confervid algæ, which separate the iron from the water to form oölite or a fine powder. Some iron ores are, therefore, of organic origin, but, as stated on p. 295, all the ores will be treated as "minerals as rocks," and found on p. 371.

METAMORPHIC ROCKS.

GENERAL REMARKS.

Metamorphism is a change in rocks of so incomplete a nature that there remain some traces of the original or intermediate conditions. Had the change been complete there would be nothing to indicate its occurrence, and we would be justified in calling the rock a primary one. Metamorphism may be further defined as a change in form, nature, or constitution, or all of them, through combinations of heat, pressure, or interstitial water (with the possible presence of "mineralizing agencies" accompanying intrusives), and is called *local* or *regional*, as it is applied to a large or small area. As far as their results are concerned they are much the same thing (Barrois). Local metamorphism occurs near and is caused by the intrusion of a hot fluid magma. The altered area is called the *aureola*. On examining it from its contact with the intrusive, where the greatest metamorphism has taken place, to its edge, where it gradually shades into the unaltered rock, we find no sudden changes in alteration where lines of demarkation can be drawn; but rather a gradual shading of one part into another by differences that are less perceptible in the broader than the narrower aureolæ. These vary in width from a few inches to four miles, and can be usually divided into a series of bands or *zones*, which occupy quite proportionate widths of the general belt, and which are characterized by peculiar minerals or forms of alteration. While these aureolæ are generally proportionate in width to the bulk of

the intrusive, they are not wholly so, as metamorphism has been found to be a matter of heat, and the substances from which the new minerals have been taken are generally grouped within a small fraction of an inch of the spot where the reconstruction has taken place, so that bulk analyses of unaltered and altered rocks show differences mainly due to loss of water and carbonic acid. The heat of intrusive masses of the same mixture may and does vary, as shown by variations in breadth of aureolæ; and while large masses may show them only on one side, a small dike in Bretagne is reported (but four inches wide) of well-crystalline *granite* and well-defined aureolæ. Here the heat increment was supplied by a long flow through the dike-walls. We must place duration of flow, therefore, as a principal agent in the case, as well as bulk of intrusive, and we must not expect to find the most decided metamorphism *always* about the largest masses of intrusive, but it will vary with the heat of the intrusive, its bulk, the duration of its flow, the composition of the walls, their bedding with respect to the intrusive, and (from these last two) the rate of heat-transmission of the walls. Other metamorphic effects are the bleaching of rocks, their coloration, induration, and the changing of clastic to crystalline texture, while the structure becomes foliated and sometimes parallel-columnar. These can be grouped as *mineralizing* and *caustic*. As both are due to heat, their extent is a measure of heat, and the great width of mineralized aureolæ about granite is as truly a sign of heat—though there be no fusing of dike-walls—as the induration of sandstone for a mile from a basalt dike, though there be little or no mineralizing. We all assent to the eruptive nature of basalt; most authorities to that of granite. The only refuge for those who deny it is to claim the region as a shear-zone, where the shear has furnished heat enough to metamorphose the country-rocks and render the

granite fluid; but this would destroy the dike-walls, and cause that shading of sedimentary to primary which is never found in nature. Granite in dikes is, therefore, eruptive if it shows a metamorphic aureola and possessed a certain amount of heat, but the valuation of that amount is differently reported. When it was thought that mineralizing was due to the introduction of new elements, it could be claimed that granite was cooler than basalt when erupted, but now that heat does the work, and as all eruptions carry "mineralizing" agencies, it becomes necessary to study the effects of heat on the vapors accompanying eruptions, and the temperatures necessary to fuse the rock classes. Barus finds that basalt fuses at 2250° F., while rhyolite (granite mixture) is viscid still at 3100° F. All authorities agree that the lower temperatures of volcanic effusion are characterized by steam, carbonic acid, etc., while the higher ones have HCl, fluoric and boric acids. Steam becomes wetter at low than at high temperatures. Dana well observes that dry heat never could indurate sandstone, but the moisture in the cooler flow of basalt would have its dissolving effect, while the hotter and, perhaps, somewhat disassociated steam of the hotter granitic flow would tend to desiccate rather than fuse, as wood has been charred by impinging steam. It may further be said that granitic outpourings were so far in the past that the internal heat of the earth had desiccated the sediments and rocks, so that there was less interstitial water than in the more recent sediments and rocks through which basalt extruded, and as moisture is a great heat-carrier, the extent of induration is due to this fact. It is generally allowed that the eurites are a granitic mixture, and the temperature of their fusion is that of granite and rhyolite (3100° F.). Cole reports a eurite dike cutting an andesitic country-rock (fusing at 2520° F.) and melting a few inches of the walls by its greater heat (?), and sending into

this melted selvage a few of its own intratelluric phenocrysts of pink feldspar, so that the cooled selvage presents the anomaly of a basaltic andesite carrying phenocrysts of pink orthoclase. A reversed example is where granite pyroclasts are included in eruptive gabbro, and the granophyre fused to a rhyolite with flow structure and spherulites. Here the cooler (?) rock fuses the one solidifying at a greater heat. The results of the study of the action of included fragments seems to show that the amount of solution depends on the dissimilarity of the rocks. Acid magmas have little or no effect on acid sediments or acid rocks, basic magmas on basic aggregates; but basic magmas will dissolve acid rocks, and *vice versa*. We may conclude, therefore, that acid magmas are hotter than basic, have their volatile components heated to the point of association as mineralizers, form large mineralized aureolæ, and exhibit little or no dissolving effect because the accompanying vapor is too highly heated for fusion, and further because the ordinary sediments are aggregations of quartz mainly, and with more acid than basic accessories, and therefore are not readily acted upon by acid magmas. Basic magmas, on the contrary, are cooler, have wetter steam and more HCl than fluoric or boric acids, mineralize slightly, and indurate readily, both from their acting upon more moist aggregates, and from the acid character of those aggregates. Owing to the greater exhibition of these effects along the line of contact of intrusive and country rock, local metamorphism is called *contact* metamorphism, and the same adjective is applied to the results of the change, as *contact* rocks, *contact* minerals, *contact* induration.

Regional or *dynamo metamorphism*, on the other hand, is the change produced over wide areas through pressure, heat, and moisture, irrespective of the presence or absence of intrusives. In equally numerous cases these latter may have

added their increment (locally) to the change, or have been involved in it. The pressure is dynamic, and not superincumbent, and has usually been the cause of the heat. The moisture has been usually interstitial. As the definition of metamorphism requires the retention of some trace of the original structure, or some evidence of a change, we must be able to trace these rocks to their original conditions, or find the evidences of alteration. The former is possible in many cases in the field; the latter is possible sometimes only through the microscope. With a ready escape for water, and with limited heat and pressure, the rocks are freed from volatile components, as gases from soft coal, CO_2 from carbonates, moisture from sediments, while the particles of the rock are forced nearer one another. Moisture allows crystallinic changes, as the rebuilding of the faces on clastic grains, so that sandstone becomes quartzite and limestone marble. Metachemism (Dana) allows the formation of new minerals from aggregates of varying composition in the immediate neighborhood. Loss of bedding structure follows and "foliation" is induced, so that the rock is no longer a sediment, but a *crystalline schist.* These are the same changes that have taken place in contact metamorphism, but applied on a grander scale, by lower heat and therefore during a longer period. Following Dana, the changes may be grouped as follows:

1. By small amounts of heat: discoloration, drying, consolidation.
2. By increasing amounts: crystallization of sediments.
3. By greater amounts: mineralization.

These are followed by incipient and (in regional metamorphism) complete fusion, with results that cannot be told from fusion due to other agencies. The resulting rocks depend on the composition of the mass acted upon as well as its inclosed moisture. Heating dry quartz would make

no change, but moist sand would become quartzite. Aluminous sediments from which the alkalies have been leached form aluminous silicates (cyanite, garnet, andalusite), but cannot form mica, which requires alkalies, as does feldspar. Crystallinic metamorphism has already been noted as rebuilding the faces of clastic grains. This is shown on a grand scale in the change of clastic limestone to crystalline marble.

Another series of similar rocks may form on varying scales through the crushing of solid rocks, as shown in a series of gneisses and other crystalline schists on the north shore of Lake Superior. From all these causes there arise rocks metamorphosed from older sediments or solid rocks. Some of them are crystalline; others crystalline and schistose; others still (as eruptive gneiss) have been heated sufficiently to become fluid, but not homogeneous, and have been erupted in this state, as shown by their aureolæ. All are equally metamorphic rocks, but there are two grand divisions—the *schistose*, and those merely *crystalline* and fused. We can, therefore, divide this class into:

I. Metamorphic *crystalline rocks.*
II. Metamorphic *crystalline schists.*

I. METAMORPHIC CRYSTALLINE ROCKS.

These are the results of incipient and (generally) of contact metamorphism, and begin with the caustic effects of burning coal-beds and of dikes, and extend through the beginning of a crystalline texture in slates to the complete crystallization of limestone through regional metamorphism. The caustic effects and incipient crystallization will be noted in Division (I*a*), and the complete crystallization in (I*b*) and Part II.

Ia. CAUSTIC EFFECTS.

PORCELLANITE, Porcelain Jasper.

A baked clay, blue, gray, yellow, brown, and red; spotted, streaked, clouded; compact, coarse-schistose, slaggy; conchoidal fracture; translucent on thin edges; dull or slightly greasy luster.

Most authorities describe this as the result of the burning of a clay-bed rich in feldspar by intrusions of trap or the heat from burning coal-beds. Geikie seems to place here the hornstone-like product of an intrusion in argillite. Porcellanite is distinguished from both jasper and hornstone by its ready fusibility, and its forming glass when heated with soda.

METAMORPHIC ARGILLITE.

The rocks produced by the variations in metamorphism are found most closely associated in contact effects, as in regional metamorphism wide areas are occupied by a variety which may be found occupying a zone of moderate width about an intrusive. Quite similar results are found about various intrusives along the outer zones, the great differences being found along the immediate contact. This is the case in the examples of metamorphism in other rocks that follow, and in this and the following descriptions the results with a highly acid magma (granite) will be followed by those of a highly basic (diabase) one. The varieties found near the contact are peculiar to contact metamorphism; those due to heat alone (moist heat) are found in regional metamorphisms also. Beginning with the outer extremity of the aureola, in this and the following cases, we find in *acid* contacts:

(*a*) *Knotty Slate.* This has the color of argillite, but in it are small darker knots or spots with indistinct margin which are shown (*m*) to be incipient staurolites and andalusites. This shades into one of the following:

(*b*) *Staurolite*-slate, where the more micaceous slate shows staurolite; *chiastolite*-slate, when it exhibits that mineral; *ottrelite* slate, with ottrelite; *dipyre* slate, with phenocrysts of dipyre. These shade into

(*c*) *Leptinolite*. Here the texture changes and the rock is like hornstone. (*m*) it is an aggregate of andalusite, staurolite, colorless mica, and other minerals dependent on the composition of the intrusive. With intrusive granite this rock shades into

(*d*) *Cornubianite* (of Bonney), when it is a fine-grained and gneissoid compound of quartz, mica, and tourmaline; or

(*e*) *Proteolite* (of Bonney), when it is a similar compound of quartz, mica, and andalusite. (*d*) and (*e*) are hard, compact rocks and with their ingredients entirely (*m*), so that they resemble (*M*) hornstone, and fall under Geikie's "porcellanite" above. When andalusite is predominant, these are called *andalusite* hornstone. In none of these last is there the perfect foliation of gneiss, so that they are better treated here than with that rock.

In *basic* contacts the outer zones are similar to the above, but the inner ones are different. As they are alike in phyllites and some shales, all will be described here, and references made under the other rocks to this description. Instead of the leptinolite, above noted, there are two rocks which vary in the arrangement of the minerals, as:

(*c'*) *Spilosite* (Zinken). Gr. 2.78. A fine-grained to compact and sometimes schistose, feldspathic mass, greenish, with gray or grayish green scales as large as flax-seeds, and weathering to a rusty brown color, scattered through it. The similar state called

(*d'*) *Desmosite* (Zinken) differs in its density (Gr. 2.81), and in the arrangement of the fresh or weathered spots in distinct bands and layers, so that there is an alternation of white and colored bands. These shade into

(*e'*) *Adinole* (Lossen). This differs from the above in its possessing a less strongly marked flat-parallel structure. It much resembles hälleflinta, but it is much more fusible. It has Gr. 2.71; silica 65–80; soda 4–10. It is a very compact, felsitic, hornstone-like rock, with conchoidal fracture, and is (*m*) fine-crystalline. It is colored green, red, and gray, and with the colors banded as in hälleflinta. All of these are varieties of "whet-slates."

These states of metamorphism are found as follows: Knotty slate, chiastolite-, and other slates in New England, Scotland, Wales, Bretagne, Pyrenees; spilosite, desmosite and adinole in the Harz, and the last also in Bretagne and Wales.

METAMORPHIC PHYLLITE.

Taking a similar example of a granite-phyllite contact, we will find similar zones characterized by similar rocks, the difference being in the greater proportion of mica. Beginning with the outer edge, as above, we find

(*a*) *Fruit*-slate. This differs from knotty slate in the brownish concretions resembling grains of corn, dried currants, etc. (hence the name). They have a slightly higher luster and seem to be made of talc or mica. The slate itself seems to have a higher luster, or rather glimmer, from the creation of a higher mica content. This shades into a fruit-slate with more mica and chlorite, and this into

(*b*) *Mica-andalusite*-slate, like a similar argillite reaction, but with more mica. This shades into the rock named above

(*c*) *Proteolite* (of Bonney), which is a compound of quartz, mica, and andalusite.

Some of the stages of metamorphism are represented by other rocks called *sericite*-phyllite (Lossen), which is a (*m*) compact, greenish, reddish, or violet sericite-schist; and *mica*-phyllite, which is a similar aggregate of mica, compact and

with silky luster. Some granite-phyllite contacts are strongly tourmalinized to form *tourmaline*-hornstone, and *tourmaline*-schist, which is a schistose state of the tourmaline rock noted under "Granite." The basic contacts with phyllite show somewhat similar states, and with similar names to *c'*, *d'*, and *e'*, under "Argillite," above. Adinole is also a state of metamorphism in shales, and is found as such in the Harz and the Taunus.

METAMORPHIC SANDSTONE.

This is first indurated. The basic intrusives form greenish colorations; the granitic whiten and mineralize, so that with the latter we find, as we approach the contact, *biotite*-quartzite, which shades into *sillimanite-biotite*-quartzite, and that to *feldspar-biotite*-quartzite, and these frequently contain garnet. Quartzite and its varieties will be fully described later. Argillaceous sandstones form porcellanite on diorite contacts. The diabase-sandstone (Trias) contact of Rocky Hill, N. J., shows tourmaline.

METAMORPHIC LIMESTONE.

The first step is the formation of marble ("marmarosis," Geikie). The crystalline product then acquires lime silicates in ordinary limestone, and additional magnesia silicates in dolomitic varieties; such as garnet, vesuvianite, wollastonite, and the others noted under "Marble." At the contact is formed a calcareous variety of the hornstone-like rock above noted, with similar appearance and fracture, called *lime-silicate*-hornstone. Some included pyroclasts have been altered to a crystalline-granular aggregate of the above minerals with abundant olivine.

METAMORPHOSED SCHISTS, etc.

These are schists and primary rocks that have been metamorphosed, and not metamorphosed sediments. Dependent

on the similarity or dissimilarity of the intrusive, slight or quite extensive changes take place. Acid intrusives make little change, beyond slightly increasing the prominence of certain minerals in acid rocks; while basic intrusives in basic rocks have still less effect. Intrusives of different composition impose on the country-rock slight changes, such as alteration of pyroxene to hornblende in granite-dolerite contacts; while basic-acid contacts show fusing effects.

Ib. METAMORPHIC CRYSTALLINE ROCKS.

CALCAREOUS.

MARBLE, Granular Limestone.

A crystalline-granular aggregate of calcite in equidimensional coarse to fine saccharoidal grains intergrown together without druses or pores; variously colored, and with or without accessories.

H. 3; Gr. 2.7–2.8.

Marble occurs in beds and lenticular masses between metamorphic schists and as contact deposits with intrusives into limestone. In some cases the process of metamorphism has softened the mass, so that its beds become swollen and appear like dikes, or are squeezed like apophyses into the fissures and cracks of the inclosing schist. The best statuary marbles come from southern Europe, but very good stone is found at Rutland, Vt. The trade name "marble" differs from the above definition in including any limestone of any texture which is susceptible of a high polish and desirable for ornamental purposes. True marbles are found in Canada, New England, eastern New York and Pennsylvania, New Jersey, eastern Maryland, Pickens County, Ga., and California, which are mainly white. Red and reddish marbles are found in east Tennessee, Vermont, Arkansas, Alabama,

Maryland, Missouri, New York, where it has been quarried, especially in the first two states, and is reported from Georgia, Colorado, North Carolina, and Wyoming. Black marble is found in Vermont, New York, Williamsport, Pa., California, Arkansas, and is reported as occurring in Colorado, Illinois, Tennessee, and West Virginia. Gray marbles occur in New York, Virginia, Tennessee, and Arkansas. When the great West has been fully explored, there will probably be deposits of this stone in the metamorphic areas. In addition to the colors already noted there are found yellow and yellowish shades, and blue and bluish varieties. The purest white and finest grained marbles in the world come from Carrara, Italy, and Paros, Pentelicon, and neighboring localities in Greece. As accessories in the United States and (*M*) are: (1) common accessories, muscovite, serpentine (especially about New Haven, Conn.), scapolite, spinel, talc, titanite, and wollastonite; (2) less common, in northeastern New York, apatite, corundum, epidote, bronzite, hypersthene, rutile, graphite, chondrodite, tourmaline, actinolite, vesuvianite, and zircon. At Muscalonge Lake fluorite crystals measuring one foot on a side have been found. These and a few others are found in New England and the eastern part of the Middle States along the regions of uplift. Freedom from, or mixtures with, these form the following varieties:

1. More or less free from accessory minerals:

(*a*) *Statuary Marble.* A pure white variety, fine-grained and firm-textured. The *Parian* marbles come from the island of Paros, *Pentelican* from near Athens, *Carrara* from Modena, Italy, *Luni* from the Tuscan coast. These are the best examples of the variety, though here and there in the quarries about Rutland, Vt., are found quite good kinds, their chief fault being too great softness.

(*b*) *Giallo-antico* is the beautiful Italian variety with ocher-yellow to cream-yellow color with whitish mottlings.

(*c*) *Sienna* Marble is another yellow Italian kind, with veins and mottlings of bluish red and (less frequently) of purple.

(*d*) *Red* Marbles. The *Mandelato* is an Italian kind, with yellowish white spots on a light red ground. *Tiree* marble, from Scotland, exhibits light shades to rose-red. *Tennessee* marble shows brownish and purplish shades, and in this background the whitish fossils stand out prominently. This last is only partially metamorphic. The "Winooski" red marble is one of the most handsome variegated marbles of the world. It is found along the eastern shore of Lake Champlain, and is harder than the Tennessee variety.

(*e*) *Snowflake* Marble is found at Pleasantville, N. Y. It is composed of snow-white crystals, some of which are over an inch long. It is reported as the strongest, most durable, and purest in composition and color of any marble in the United States.

(*f*) *Blue* Marbles. A turquois-blue variety is found at Seravezza, Italy, a dark blue at Gouverneur, N. Y., and a blue black at Glens Falls in the same State.

(*g*) *Anthraconite* (v. Moll), Lucullite, Nero-antico. A black marble found in nests and veins in other rocks, and (infrequently) in beds. Its color is due to carbon, as is shown by its burning white. Black marbles are reported (see above) in the United States, but there are no extensive workings. Anthraconite in beds is found near Christiania.

2. With accessory minerals:

(*a*) *Cipolino.* An easily weathering white marble with abundant pale greenish mottlings and shadings from talc and mica. These accessories become so abundant as to impart a distinct cleavage to the rock, and an increase in mica forms a transition to calcareous mica-schist. It is found in Saxony, Piedmont, Greece, and along the Green Mountains of Vermont.

(*b*) *Ophicalcite* (Brongniart), Verde Antique, is a white marble clouded with green from serpentine. It also exhibits yellowish and bluish shades. The serpentine is in grains, nests, and stains, thoroughly intermixed with the calcite. This is interesting as being the home of *Eozoön*. It is found in Canada and New England (especially about New Haven, Conn.), and in Warren County, N. Y.

(*c*) *Calciphyre* (Brongniart) is a marble porphyritic from phenocrysts of garnet, vesuvianite, and augite.

(*d*) *Hislopite* (Haughton), from Talki, in the East Indies, is a highly glauconitic marble.

(*e*) *Predazzite* is a compound of marble and brucite, and occurs at Predazzo, Tyrol.

In addition to the above, marbles may carry so high an amount of certain minerals as to be styled *tremolitic*, *graphitic*, *chloritic*, *chondroditic*, etc.

Dolomite also forms a marble, but it crumbles from weathering, as the calcite content dissolves faster than the other and undermines the structure.

II. METAMORPHIC CRYSTALLINE SCHISTS.

In this division are included rocks with but slight schistose structure, as they are found associated geologically with the schists rather than with the contact formations. At times, however, some of their varieties may be found in small zones in contact aureolæ. Under the various rock classes will be found all variations in metamorphism, from the state where the original bedding and fossiliferous content can be distinctly traced, to the almost *meta*-granites, which retain slight evidences of their metamorphism, but have lost all traces of original condition. All of these are more or less foliated, and shade from the highly developed foliation of the general body of the group towards the failing of foliation through

its shading into bedding, on the one hand, and through its obliteration from almost perfect fluidity of the highly metamorphic mass, on the other. We thus find schists varying from the incipient cleavage of claystones through slates, crystalline and foliated phyllites, to mica-schist and fine-grained gneiss. The foliation of these rocks is usually curved and crumpled, but in the less altered rocks it is flat-parallel, with the layers unlike the laminæ of strata in being flat-lenticular instead of flat-plane. In cases of a secondary metamorphism imposed on schists there is a secondary foliation that can be readily distinguished. New England is an excellent field to study metamorphism, and especially along the Green Mountains, where sediments can be traced into schists within limited areas, and secondary foliation is noted in Berkshire County, Mass.

The term "schist" is sometimes loosely used to describe coarse clastics which have been more or less bent, but which have not become crystalline-granular. It is not so used in these pages, but refers only to those crystalline-granular rocks which are foliated. All crystalline rocks without foliation are "rocks." This has already been stated, but it is repeated here, as the following pages will contain descriptions of crystalline rocks (so called) which are found with schists, but are unfoliated, or but slightly crumpled. It remains to say that cleavage is not taken as foliation. Both may be due to the same or similar causes, but the argillites and phyllites will be classed with the "rocks," and the mica-schists, into which they shade by regular gradations, will fall into "schists." In German the same word (*schiefer*) is used for schists, slates, and shales, though they are separated in classifying rocks, and occasion some trouble to the beginner who consults books in that language.

Summing what has been said of the origin of schists and adding thereto, we find that they may come: from the original crust (?) of the molten globe; as true eruptives in the

early geological ages; as tuff states (?) of old eruptives; or as sediments altered by deep burial, metachemism, or orogenic action. The results will be so similar that no division can be made from hand specimens, and the eruptive origin can only be seen in the contact aureola of the rock. We can divide them roughly according to the mineral components, as in the eruptive rocks, but less closely, as there is a broader mixture of minerals, owing to the varieties of origin and amounts of metamorphism. Those having predominant quartz and with silica over 55 per cent will be classed as *acid*, while those with a lower silica content will be grouped as *basic*.

ACID SERIES.

The rocks of this series are more or less foliated, crystalline-granular, generally (*M*) compounds of quartz, feldspar, mica, with various accessories; coarse and fine-grained and (*M*) compact; massive or fissile; variously colored.

Silica 55–82; Gr. 2.6–3.2.

They can be divided, according to the predominant minerals, as follows:

QUARTZ GROUP:

Quartzite, quartz-schist, itacolumite, Lydian stone.

QUARTZ-MICA GROUP.

Mica-schist and its varieties.

QUARTZ-TOURMALINE GROUP:

Tourmaline-schist, tourmaline-hornstone.

QUARTZ-IRON GROUP:

Itabarite, micaceous iron-schist.

QUARTZ-FELDSPAR GROUP:

Granulite, gneiss and its varieties.

QUARTZ-FELDSPAR-MICA GROUP:

Hälleflinta, porphyroid, (adinole).

FELDSPAR-MICA GROUP:

(Cornubianite).

Adinole and cornubianite have already been described, and are included in the above to show where they would come in the series if their connection with contact products did not place them in a previous series.

QUARTZ GROUP.

QUARTZITE.

A granular to compact aggregate of quartz with coarse-splintery, conchoidal, and vitreous fracture, and with few or no signs of foliation.

This occurs in beds with crystalline schists, and in some cases hundreds of feet thick. It also occurs in regions of sediments where crystallinic metamorphism has filled the interstices of a sandstone to form a compact rock. Both kinds are generally associated with the oldest formations. Quartzite is found along the Appalachian region of the eastern United States. It is generally white, sometimes yellowish white, yellow, red, and blue. The grains can generally be distinguished (*M*); but sometimes the rock is so fine that they can only be seen (*m*), and it resembles the Arkansas *novaculite* when white, and some flints when colored. It is a true sediment, and retains its bedding and other characteristics. The quartzite of South Bethlehem, Pa., has almost lost its original habit, and breaks with a conchoidal fracture, while its lower portion is porphyritic with feldspar phenocrysts. The same rock twenty miles to the southwest, at Fleetwood, Lyons, etc., is the crumbly Potsdam sandstone with unchanged bedding planes and riddled with casts of *scolithus*. The South Bethlehem rock is light or dark gray; the Fleetwood rock white, yellowish, or reddish. Quartzite also occurs as a contact formation with intrusive dikes, and forms a zone of a few feet in thickness. In still further cases the rock seems to be solid (*M*) quartz, of great purity and high translucence—almost becoming subtransparent, and exhibits a highly developed flat-parallel cleavage. It frequently shows well-developed cubical jointing. As accessories occur (abundantly) chlorite, magnetite, pyrite, and specular hematite. The last occurs

in hand specimens in Virginia in thin plates parallel to the cleavage of the quartzite. Other accessories are carbon, graphite, rutile, apatite, tourmaline, garnet, cyanite, mica, ottrelite, etc. The last occurs in a fine blue quartzite near Rutland, Vt., the color showing strongly when the rock is wet, and fading when dry. As varieties are:

(*a*) *Oölitic* Quartzite. In concretions weighing several hundredweight in the "sandy barrens" of Center County, Pa., in the limonite mines. The same form is reported from Sumatra. The variety shows spheroidal grains one-twelfth of an inch in diameter. The Center County variety may be a replacement of calcite by silica, as the "barrens" are formed by the leaching of the former mineral from the calciferous sand-rock.

(*b*) *Buhrstone* (Hitchcock) is a similar rock as far as origin is concerned, and forms a compact quartzite with irregular pores that occurs in Berkshire County, Mass., and along the Appalachian border from South Carolina to Georgia. The rock is more mineralogical than economic, as it is not worked, the best millstones of the United States being from the Berea (O.) grit. The best buhrstones come from France.

These two varieties have been described under organic aggregates of silica, but are again noted, as their organic origin is only probable. The various accessories named above are frequently predominant enough to form varieties bearing their names, as *tourmaline*-quartzite, etc.

QUARTZ-SCHIST.

A foliated quartzite, usually with some mica.

This may be taken as a mica-schist with the silica in excess of 82 per cent, but with sufficient mica to impart a schistose structure. A failure of the mica places the rock in "quartzite," and an increase of the mineral in "mica-schist." Geikie notes large tracts in the Scottish Highlands

where the rock is a transition between quartzite and mica-schist, and varies from one extreme to the other—the mica allowing the rock to be split into flagstones. In the Green Mountains of Vermont quartz-schist occurs, and with a further change (by the entrance of calcite) into calciferous quartzite and calciferous mica-schist. In the same region also occurs:

Conglomerate Schist. This is a transition between a quartz conglomerate and a gneiss. The pebbles of the conglomerate are sometimes only slightly flattened, and may reach several inches in diameter. They are then inclosed in a schistose matrix, so that they can be readily distinguished from an unaltered conglomerate. In other cases the rock has been so strongly compressed that the pebbles are flattened to long lenticules with rounded ends, and still further metamorphism changes them to lenticular folia of crystalline quartz, with no traces of their original shape. This is reported from the Alps, Saxony, Norway, France, Ireland, Scotland, and the Green Mountains.

ITACOLUMITE (v. Eschwege), Flexible Sandstone.

A fine-grained and schistose aggregate of quartz, rendered flexible, when in moderately thin plates, by parallel laminæ of mica, talc, chlorite, and sericite.

This was first described at the mountain Itacolumi in Brazil, where the formation is of great thickness and extends several miles—the mountain being 5400 feet high. It also occurs in the Southern Atlantic States of the Union and in Pennsylvania. Some authorities class this as a sandstone. As accessories are micaceous hematite, magnetite, martite, native gold, and diamond.

LYDIAN STONE, Siliceous Schist, Phthanite (Haüy), Touchstone.

A cryptocrystalline aggregate of quartz, with clay, carbon, and oxide of iron; black or dark-colored; hard; infusible; with splintery fracture.

This occurs in thin bands in, and later than, the Silurian, and appears to be an original and not a metamorphic rock, as the beds with which it is intercalated are not altered. It also abounds in fossils (graptolites, for example); but its general appearance is that of a schistose rock. It can be placed here or with sandstone with equal propriety. It is reported from the Carbonic of the Appalachian area. It was formerly used in distinguishing native metals and their alloys by their streaks on the fine dark surface.

QUARTZ-MICA GROUP.

MICA-SCHIST, Mica-slate.

A schistose aggregate of quartz and mica in widely varying proportions.

Silica 55–82; Gr. 2.7–3.17.

It occurs in extensive formations in the metamorphic areas of the world, and as inner contact zones of great width about bosses of granite, and is found in the Archæan formations throughout the world. It is always crystalline and foliated, but varies in almost every other character, as the mica varies from the condition of an accessory to that of being almost the sole ingredient. The texture sometimes becomes so slightly foliated that the rock becomes almost wholly granular-massive. The two ingredients frequently are not equally mixed, but aggregate, in folia of varying thickness, to form a flat-parallel structure. At times the mica is in knots of varying size which are connected in the quartz matrix by strings of mica. In other varieties the

quartz forms large plates, strings, or segregations about which the mica is grouped. There are few rocks in which so great a variety of arrangement of ingredients and of structures exist. The mica is usually muscovite or biotite—more generally the former, which is of white color. The greasy varieties (formerly thought to be talc) were found by Dewey to be damourite, and varieties carrying them were named by Dana *hydro*mica-schists. It happens frequently that both biotite and muscovite are together, to make a mottled rock. The quartz is in grains or larger aggregates, as already noted. As accessories occur abundantly calcite, feldspar, garnet, tourmaline, hornblende, andalusite, iolite, staurolite, chlorite, rutile, graphite, iron ores, talc, and cyanite, so that varieties are formed through them. In the contact zones about granite occur also sillimanite, fibrolite, and epidote. The various textures and structures form another class of varieties, so that from the above many are noted by various authorities. Especially prominent are:

(*a*) *Damourite*-schist, *Hydro*mica-schist (Dana). This is a soft rock with damourite or one of the hydromicas replacing mica. It occurs as alterations of older rocks, such as crushed diorites, and as beds in slightly metamorphic sediments. In eastern Pennsylvania there are two damourite beds, the lower being between the Potsdam sandstone and the gneiss, and the other between the Hudson slates and the Silurian limestone. This forms the matrix of the subglacial till along the northern border of the South Mountain, at Bethlehem, Pa. It also is found along the Taconic region, in Canada, and along the Laurentian of the Atlantic States. It is usually in light colors, that just noted being shades of cream. The compact state is called *agalmatolite*. It occurs in the Alps as *paragonite*-schist, when this form of mica is predominant.

(*b*) *Calcareous* Mica-schist. A fissile, crystalline-granular aggregate of quartz, mica, and calcite, of all degrees of coarseness, and all extents of variation in the proportions of the components. The variety from the Erzgebirge is a foliated limestone, and a transition between cipolino and mica-schist. In the eastern Alps the rock consists of alternate layers of mica-schist and limestone. The varieties of central Vermont are a most intimate mixture of the ingredients in variable proportions. At times there is a fine-granular and slightly foliated mixture in which quartz is predominant, so that it resembles a slightly micaceous calciferous sand-rock on a fresh fracture, but the weathered specimens show the difference in composition to a high degree, as they lose their calcite and leave the quartz deeply rusted from the decomposed mica, so that the weathered stone can be readily crumbled with the fingers, and forms "rotten stone." Other varieties in the same region consist almost entirely of mica (predominant), and large knots or concretions of cream-colored calcite or dolomite, drawn out to form "eyes" in the dark mass. A third variety shows predominant quartz with calcite and subordinate mica. The calcite exhibits cleavage surfaces on a fracture, some of which are $\frac{1}{4}$ inch across. The variety at Woodstock, Vt., abounds in garnet of all sizes up to that of the fist. Other accessories are tourmaline, hornblende, epidote, magnetite, graphite, and talc—the last sometimes replacing mica to form calcareous talc-schist.

The following varieties are also worthy of note: *chloritoid*, from the Alps; *tourmalinic*, from Saxony, the Green Mountains, etc.; *double mica*, *nacritide* (Schill), with both micas, from Saxony, Pike's Peak, Kansas; *gneissic*, from the Erzgebirge; *garnetiferous*, a common variety; *graphitic*, from Saxony, the Pyrenees, Norway, etc.; *andalusitic*, from Sweden, Spain, Ireland, Tyrol, etc. Many of these are

found in New England. *Hornblendic* mica-schist will be noted later under "Hornblende-schist." An *epidote-glaucophane*-mica-schist is reported from the island of Celebes.

QUARTZ-TOURMALINE GROUP.

TOURMALINE-SCHIST.

A foliated granular aggregate of quartz and tourmaline.

This is not the schistoid state of the compound of quartz and tourmaline noted under "Granite," but a contact product of granite. In this rock the tourmaline is in granules and acicular crystals, and the rock as a whole is fine-granular and black. While tourmaline-quartzite and tourmaline rock are formed from the *granite* by the influence of the boric and fluoric acids, this and the next rock are formed by similar agents from the *country-rock*. Tourmaline-schist occurs, therefore, as an inner contact zone of an intrusive granite with phyllite and similar rocks, and is found in Cornwall, in the Erzgebirge, and elsewhere.

TOURMALINE-hornstone.

A (*M*) compact aggregate of quartz and tourmaline with mica, staurolite, iron ores, etc.; with splintery fracture; slight foliation; grayish color.

This is the tourmaline representative of the ordinary hornstone formed in granite contacts without exhalations of the above-noted mineralizing acids, and the similar lime-silicate-hornstone of the contacts with limestone. (*M*) it cannot be told from the above when compact, and it is only by following it into parts of the aureola where tourmaline appears (*M*) that the variety can be known. It is readily told when examined (*m*). It is found in Cornwall, Saxony, Bretagne, Norway, and at Mount Willard, N. H.

With this formation of tourmaline there is also a growth of topaz, so that in the breccias of tourmaline-quartz-schist there occur nests and veins of topaz (crystal, granular, compact), as on the granite-phyllite contact of the Schneckenstein in the Voigtland, to form "topasbrockenfels."

QUARTZ-IRON GROUP.

ITABIRITE (v. Eschwege).

A granular to compact aggregate of quartz, micaceous hematite, and magnetite.

It appears to be a highly ferruginous mica-schist, and with itacolumite forms Mount Itabira in Brazil. It is also found in the Carolinas, at Sutton, Canada, Norway, and on the Gold Coast of Africa. It is black and violet in color, and has the iron ores as predominant minerals, with quartz sometimes quite an unimportant ingredient, while at other localities the quartz forms white lenticular strings, so that the mass has a decided schistose appearance. As accessories occur talc, chlorite, hornblende, biotite, garnet, gold, epidote, and feldspar. On weathering it forms a sand called *jacotinga*.

MICACEOUS IRON-SCHIST.

A granular schistose aggregate of quartz and micaceous iron.

It occurs in beds in metamorphic regions, and is found in Brazil, Hungary, South Carolina, etc. The quartz is in white grains (usually grayish white), scattered between the folia of micaceous hematite. These latter are black, and so evenly arranged that the rock seems dotted with white in stripes. In the iron region of Virginia, near Lynchburg, a similar rock appears with the two minerals in masses, the quartz being predominant and the hematite forming plates an inch broad, so as to impart a somewhat flat-parallel structure to the rock.

QUARTZ-FELDSPAR GROUP.

GRANULITE (Weiss), Leptynite (Haüy).

A slightly foliated fine-grained aggregate of granular quartz and feldspar, usually with small garnets.

Silica 70–80; Gr. 2.6–2.7.

This is a gneiss without mica, and occurs locally in Archæan formations. It is especially developed in the eastern part of North America. In Canada it is known locally, north of Lake Ontario as "huckleberry rock." The Second Geological Survey Reports of Pennsylvania place here the non-garnetiferous mass of the South Mountain at its eastern extension between the Delaware and Schuylkill rivers. At times the foliation is so indistinct that it might be called aplite, were it not for the presence of garnet. The quartz is white, and occurs in grains and strings, which give a schistose appearance to the mass. The feldspar is usually orthoclase (microcline, microperthite) of pale reddish, yellowish, or white color; or plagioclase (oligoclase) in rare cases. Garnet is red, and from (*m*) proportions to the size of peas, rounded or roughly crystal, sometimes flattened like the quartz till as thin as a sheet of paper, and forming reddish specks on a fracture parallel to the foliation. Among the accessories is biotite, which makes transitions to gneiss, so that we can have the two intermediate rocks *biotite*-granulite and *gneiss*-granulite. The following accessories are frequently so abundant as to form rocks with similar names, as *cyanite*-granulite, *garnet*-granulite, *tourmaline*-granulite. The variety in eastern Pennsylvania can be called *hornblende*-granulite, as it varies between that rock and hornblende-gneiss. *Pyroxene*-granulite, *hypersthene*-granulite, and *diallage*-granulite are basic forms occurring in Saxony. If mica occurs, it is usually dark brown to black (Zirkel); "usually a white variety of mica, seldom black" (v. Cotta).

The ordinary granulite is white, yellowish, or flesh-red, with garnet and cyanite (Rosswein, Saxony); *striped* granulite has the components in parallel stripes (on the Zschopau, Saxony); *black* granulite, from iron (Penig, Saxony). The rock is characterized by regular jointing parallel to the foliation, and an irregular cross-jointing with smooth partings. The Pennsylvania rock shows abundant slickensides as large as the palm of the hand.

QUARTZ-FELDSPAR-MICA GROUP.

GNEISS (old miner's term for the rock containing the ore).

A schistose granular aggregate of quartz and feldspar (potash, soda, or lime-soda) with one of the black bisilicates, preferably the micas. A foliated granite.

Silica 56–75; Gr 2.6–2.8.

It occurs in widespread masses in the Archæan formations of the earth, especially in Scandinavia, Scotland, and the eastern part of North America, where it forms a V-shaped area extending from Labrador to New York, and thence by the north shore of Lake Superior to the Arctic Ocean, with a narrow tongue southward from New York to Alabama along the Atlantic coast. There are extensive masses in New England also. The Adirondacks and White Mountains abound in varieties. The great seaboard cities of the eastern coast—New York, Philadelphia, Baltimore, and Richmond —are built on gneiss. In the western part of the Union it forms the axes of extensive mountain chains, and the centers of raised regions. Gneiss is generally a highly metamorphic sediment that has sometimes become eruptive (Scottish Highlands), and exhibits contact aureolæ; also metamorphosed states of crushed granites and other acid rocks (Alps, north shore of Lake Superior, etc.). It differs from

granite in its foliation and in the more granular texture of the ingredients, which are not interlocked into one another, but are more distinct, and occur in banded and foliated structures, the mica laminæ and other unequiaxial minerals (tabular feldspars, tourmaline, hornblende, lenticular aggregations, concretions, etc.) having a parallel arrangement which allows cleavage along the foliation, and more readily along the layers of mica. The feldspar is usually orthoclase in crystalline grains of the lighter colors of the granitic mineral, except the decided red, which is only found when it is stained with ferric oxide. It frequently occurs as phenocrysts to form *porphyritic* gneiss, and in some cases is in twinned forms half a foot in length. Microcline is of frequent occurrence, and sometimes microperthite. Plagioclase is sometimes greenish from epidotizing of pyroxenic ingredients. Oligoclase and albite are common, but usually as phenocrysts and not in the general mixture; labradorite is very rare. Quartz occurs in grains and lenticular strings, which latter sometimes form bands of great purity one foot wide, with parallel folia of mica scattered through them. As inclusions in quartz occur feldspar, biotite, fine acicular rutile, epidote, zircon, graphite, etc. Pegmatitic structures occur which vary from the ordinary in being poikilitic, as feldspar is highly predominant. As in granite, the mica is muscovite and biotite in irregular folia, but of more rounded contours. Biotite is green, with inclusions of garnet, epidote, zircon, etc., and alters to chlorite and epidote. Muscovite is colorless or light shades of green and gray. As stated under the description of minerals, the two are intergrown as alternate laminæ of an aggregation, or as parts of the same folia. As essentials occur tourmaline in prisms and acicular crystals, single or aggregated, and sometimes four inches long; occasionally in rounded grains. Hornblende occurs in biotite gneiss, and is associated with that mineral

as in granite. It is generally of light colors, or not of very dark ones. Sometimes glaucophane is found. Pyroxene occurs under the same conditions as in granite, and is found in plagioclase-gneiss accompanied by few accessories. Hypersthene sometimes occurs with labradorite and biotite. Iolite is found in bluish grains and forms the variety "cordierite"-gneiss. Garnet is one of the most common accessories, and is more abundant (*M*) than in granite, but much less so than in mica-schist. It shows red and brown colors. Sillimanite, fibrolite, andalusite, and staurolite are abundant in micaceous gneiss, but less so than in mica-schist. Less frequently occur epidote, apatite, zircon, titanite, magnetite, graphite, chlorite, etc. Lenticular aggregates of orthoclase or microcline alone, orthoclase with mica coating, tourmaline and quartz, glaucophane in dark blue knots, etc., also occur. The varieties are:

(*a*) *Typical* Gneiss, *Mica*-gneiss. In this the black bisilicate is one or both of the micas. Variations are *muscovite-*, *biotite-*, and *muscovite-biotite*-gneiss. Predominant mica of either kind forms *micaceous* gneiss. Variations in the texture and structure of the mica varieties form the states known as *granite*-gneiss, where the foliation is so indistinct as to be almost lost; *porphyritic-* or *augen*-gneiss, where phenocrysts or eye-shaped kernels of feldspar are scattered through the mass; *wood* gneiss, where the ingredients are arranged in fibrous-parallel structure, as in wood, so as to supersede the schistose structure; *slate*-gneiss, where the texture is fine and mica is predominant, so that a decided cleavage is formed; *ribbon* gneiss, where quartz, feldspar, and mica are aggregated in thin and mutually alternating layers, which give, on a cross-section, the striping of a ribbon; *giant* gneiss is the schistose form of giant granite, where the ingredients are respectively an inch in size; *red* gneiss, with silica 74–76, feldspar orthoclase and predomi-

nant, mica always white and not abundant; sometimes eruptive; *gray* gneiss, with silica 64–67, mica dark and predominant, feldspar orthoclase and oligoclase.

(*b*) *Cordierite*-gneiss is a variety of biotite-gneiss where iolite (cordierite) is abundant with gray quartz and much feldspar. It is usually of dark color. It occurs in Saxonv, France, Scandinavia, etc., and at Guilford, Conn.

(*c*) *Granulite*-gneiss has little mica, and that usually white. V. Cotta states that it always belongs to the red gneiss.

Other varieties of the mica-gneisses are made by predominant fibrolite, garnet, graphite, epidote, talc, and iron ores. Where the mica is more or less replaced by other minerals, other variations of greater value and extent occur, as:

(*d*) *Sericite*-gneiss is an aggregate of quartz, albite, and sericite, with now and then white or black mica in small amounts, and a chloritic mineral. It occurs in the Taunus, in Japan, etc.

(*e*) *Protogine*-gneiss is a decidedly schistose state of the schistoid protogine-granite already noted. It consists of an aggregate of white or reddish orthoclase, greenish white plagioclase, and quartz with a talclike mineral. A variety of this is *chloritic* gneiss. It is widespread in the Alps, and was called "alpenit" by Simler.

(*f*) *Hornblende*-gneiss, Syenite-gneiss, etc. This is a gneiss with hornblende more or less replacing mica, which is biotite rather than muscovite. The feldspar also changes, and instead of predominant orthoclase, oligoclase and other plagioclases appear. With orthoclase we have "syenite"-gneiss, with plagioclase "diorite"-gneiss, and with plagioclase and mica "tonalite"-gneiss. Pyroxene appears in this variety and alters to chlorite and epidote. The varieties of hornblende-gneiss are very abundant in the Archæan areas, and the Pennsylvania gneiss of the eastern middle part of

the State is *granulite-hornblende*-gneiss, with accessory allanite, molybdenite, and considerable magnetite, which forms extensive ores in New Jersey. Anthophyllite and glaucophane are frequently abundant enough to form varieties.

(*g*) *Pyroxene*-gneiss. This is an aggregate of predominant plagioclase (albite, oligoclase, labradorite, and anorthite) with some orthoclase and quartz and a light-colored pyroxene. As accessories are wollastonite, scapolite, occasional calcite, biotite, garnet, titanite, and frequently hornblende. Occasional combinations are omphacite and bronzite, saussuritic feldspar, etc. This variety can be called from its feldspar *plagioclase*-gneiss and *anorthite*-gneiss, and when the pyroxene is hypersthene it may be called "norite"-gneiss; when diallage, "gabbro"-gneiss; when augite, "diabase"-gneiss; or all the minerals can be used as a prefix, as *hypersthene-anomite plagioclase*-gneiss, *diallage*-gneiss, *augite*-gneiss, *wollastonite-augite*-gneiss, *scapolitic augite*-gneiss. Augite-gneiss is found in Scandinavia, Spain, Bretagne, Vosges, etc., and in Minnesota, Wisconsin, and New York.

QUARTZ-FELDSPAR-MICA GROUP.

HÄLLEFLINTA.

A (*M*) compact homogeneous rock with an appearance like hornstone, a splintery to conchoidal fracture, and color varying in bands of gray, green, yellow, dark brown, to black. It fuses only on thin edges. It may be considered, in some cases, as a compact gneiss, in others as a devitrified rhyolite.

Silica 61–83; Gr. 2.65–2.78.

This occurs in Sweden with granulite and gneiss, into which it can at times be traced, but Nordenskiöld has recently described occurrences of it as a devitrified rhyolite, where it exhibits the flow structure, lithophysæ, etc., of that

rock. It is fine-crystalline (*m*), and shows an intimate mixture of quartz and feldspar, with scales of mica and chlorite. We have, therefore, two origins for the same rock—the metamorphic form of fine sediments which have become a compact gneiss, and the devitrified form of an extrusive glass. Hälleflinta much resembles adinole and porphyroid. A porphyritic hälleflinta was found to be a devitrified quartz-porphyry. It is also found in Bavaria, Baden-Baden, and the northwestern part of South America.

PORPHYROID.

A rock with felsitic groundmass; somewhat schistose from the development of micaceous scales, and exhibiting sporadic phenocrysts of quartz and feldspar.

Silica 75–83; Gr. 2.6–2.75.

It is found among the schistose rocks of Saxony and in the Paleozoic areas of other parts of Europe, and is thought to be an orogenic product from extensive shearing and subsequent rearrangement of material. It resembles a schistose and micaceous quartz-porphyry, and is like adinole in its appearance and behavior. The feldspar is orthoclase or albite in quite perfect crystals, and the quartz is frequently in double pyramids. The mica is paragonite or sericite (both belonging to muscovite). With a coarser grain the rock would become a highly crystalline gneiss. It so much resembles the rock last noted that some authorities call it a "porphyritic" hälleflinta. It occurs in the northern peninsula of Michigan in the Huronian formation, and in Nevada.

BASIC SERIES.

The rocks of this series are more or less foliated, crystalline-granular, generally (*M*) compounds of pyroxene, amphibole, garnet, talc, chlorite, serpentine, with feldspar (usually plagioclase), quartz, and various accessories; coarse- and fine-grained, and (*M*) compact; massive or fissile; variously colored.

Silica 26–58; Gr. 2.7–3.5.

They can be divided, according to the predominant minerals, as follows:

MARGAROPHYLLITE GROUP:

Talc-schist, *calcareous* talc-schist, listwenite, dolerine, rensselaerite, steatite, potstone, chloritic potstone.

Chlorite-schist, uralite-schist, chloritoid-schist.

Pyrophyllite-schist.

EPIDOTE GROUP:

Epidosite, epidote-schist.

GARNET GROUP:

Garnet rock, eclogite, cyanite rock, kinzigite.

AMPHIBOLE GROUP:

Amphibolite, hornblende-schist, actinolite-schist, glaucophane-schist, green schist.

PYROXENE GROUP:

Pyroxene rock, pyroxene-schist, erlan.

OLIVINE GROUP:

Olivine rock, olivine-schist, eulysite.

MARGAROPHYLLITE GROUP.

TALC-SCHIST.

A schistose aggregate of talc with quartz and (less frequently) feldspar, and other accessories, the talc is predominant in yellowish or greenish scales; soft; with pearly luster and greasy feel.

Silica 27–62 (average 50–55); Gr. 2.6–2.8.

This occurs in beds of considerable size, but not very widely spread, and is found in the Urals, Alps, Apennines, in Brazil, Canada, New England, and along the Archæan formation of the Atlantic coast. Quartz occurs in grains, lenticules, and strings parallel to the foliation. Other accessories are micas, chlorite, actinolite, calcite and other carbonates, magnetite, pyrite, and, less commonly, garnet, olivine, tourmaline, asbestus, rutile, cyanite, staurolite, and others. It is a metamorphosed sediment, and shades into protogine-gneiss, chlorite-schist, clay-slate, mica-schist, and similar rocks. As varieties are:

(*a*) *Calcareous* talc-schist. This bears to this rock the same relation that calcareous mica-schist bears to mica-schist. It is a less common rock, but is found in similar formations, as along the Green Mountains, in New England, etc.

(*b*) *Listwenite* is a granular talc-schist, with yellowish greenish color, from the Urals, and carrying much quartz and calcite, so that it shows a fine-granular-slaty structure. With the calcite is dolomite, and sometimes siderite. In some varieties the quartz fails. This is the rock penetrated by beresite.

(*c*) *Dolerine* (Jurine) is a talc-schist from the Pennine Alps with essential feldspar and chlorite.

(*d*) *Rensselaerite* (Emmons) is a pseudomorph of talc after pyroxene that is found in northern New York and Canada, especially at Hermon, N. Y. It is associated with crystalline limestone, and shades imperceptibly into serpentine. It is seldom found in large masses: they are irregular and up to 900 to 1000 feet long. It is cryptocrystalline and waxlike in composition, with colors whitish, yellowish, gray, greenish, and pearl-white.

(*e*) *Steatite*, Soapstone, is a massive talc, coarse-granular, grayish green, gray, and brownish gray. This frequently

contains chlorite, and then forms what some authorities call "talcose potstone." One of the principal quarries in the United States is a few miles northwest of Easton, Pa.; another is near Philadelphia in the same State.

(*f*) *Potstone* is a soft, sectile, greenish gray aggregate of talc, chlorite, and serpentine in a feltlike web. It is rarely foliated. It is infusible, and frequently carries as accessories mica, calcite, dolomite, magnetite, and pyrite. These sometimes cause effervescence with acids. It is an impure steatite, and is found in New England, Canada, and New York. It is used for making cooking-pots, and was so used by the Indians.

(*g*) *Chloritic* Potstone is a variety that carries predominant chlorite, and is therefore a transition to that mineral. It is found with steatite.

CHLORITE-SCHIST.

A granular to schistose aggregate of scaly chlorite with quartz, and sometimes feldspar, talc, mica, epidote, and magnetite.

Silica 26–50; Gr. 2.7–3.

This occurs with gneiss and other schists in bedded masses, and is found in Austria, the Alps, Tyrol, Italy, Asia Minor, the Urals, Brazil, Transvaal, and in the Southern Atlantic States. The chloritic mineral is one of that group, and is predominant. It gives the green or blackish green color and grayish green streak to the rock. It is usually soft and coarsely foliated, and with little quartz. Abundant quartz forms a more granular rock with greater hardness, and sometimes occurs in folia, lenticules, irregular strings, or thin veins that traverse the rock in all directions. It shades into talc-schist, protogine-gneiss, argillaceous mica-schist, and slaty serpentine. The coarser schistose states

are sometimes called *chloritic gneiss*, while the finer and more even and silky kinds are *chlorite-slate.*

(*a*) *Uralite-schist* (Kantkiewicz) is a coarse-schistose aggregate of (*m*) fine-grained chlorite and epidote with accessory quartz and biotite, and with (*M*) phenocrysts of augite-like uralite. It alters to a green chloritic mineral. It is found in the Urals.

(*b*) *Chloritoid Schist* (Sterry Hunt) is a dark-colored schist of considerable extent in Canada, composed of a chloritoid mineral allied to chlorite and to ottrelite. It also occurs near Salzburg, and in Roumania.

PYROPHYLLITE-SCHIST.

A compact and but slightly schistose aggregate of pyrophyllite.

Silica 65.93; Gr. 2.82–2.91.

This is a rare occurrence as a rock, and is found thus in North and South Carolina, Georgia, and Arkansas, where it forms schistose to compact beds of greenish to yellowish white color, resembling in appearance and feel a slaty soapstone. It is generally free from accessories, and forms a smooth and evenly soft rock, microcrystalline to aphanitic, that is extensively worked for slate pencils.

EPIDOTE GROUP.

EPIDOSITE (Pistacite Rock).

A yellowish green, light green, to dark green aggregate of predominant epidote and quartz, with an amphibole, mica, or chlorite, and, less frequently, feldspar and pyroxene; hard; massive to schistose; granular to compact; tough.

Silica 62; Gr. 3–3.4; H. 7.

It occurs associated with crystalline schists, and also as an alteration product from an eruptive, and is found in

Brazil (?), at several localities in Canada (St. Joseph, Grand Manatee River, Melbourne), Greece, island of Anglesea, etc., and as the alteration product of a melaphyre in northwestern South America. It is also reported from Portage Lake, Wis., as a similar product. The Canadian textures are compact to coarse-grained. The varieties are:

(*a*) *Glaucophane*-epidosite. From the island of Syra, with a yellowish white principal mass of fine epidote, with zoisite, mica, and chlorite, in which are somewhat stout glaucophanes.

(*b*) *Omphacite-zoisite* Rock, from the same island, has the principal mass of grains of zoisite with phenocrysts of omphacite, and as accessories are leaves of talc, grains of epidote, stout prisms of tourmaline, folia of chlorite and biotite, and (*m*) rutile and calcite.

EPIDOTE-SCHIST.

A schistose aggregate of the above minerals with similar silica, specific gravity, and other characteristics.

This is associated with the above rock, and forms transitions into it. The variety of the island of Timor shows as accessories sericite, magnetite, quartz, calcite, plagioclase, and specular hematite, and has a greenish color and silvery luster on the foliation surfaces. As varieties are:

(*a*) *Hornblende*-epidote-schist. From the phyllite formation of the peninsula of Chalcidice. It is a fine-grained aggregate of coarse epidote, bright green hornblende, and tufts of chlorite.

(*b*) *Mica*-epidote-schist, in dark-green thin foliated structure, with predominant epidote, quartz, green biotite, and iron ores, with variations where quartz and mica were each predominant.

(*c*) *Calcareous* Epidote-schist, "Kalkpistacit"-schist (Porth). From northeast Bohemia, with a principal mass

of calcite, epidote, and mica, with accessory albite, quartz, iron ores, and pyrite. This is the parallel of calcareous mica-schist, etc.

(*d*) *Murasaki* (Kotō), Manganese-epidote-schist, from the island of Shikoku, Japan, is a violet rock of small quartz grains with phenocrysts of epidote ½ inch long, with accessory sericite, greenish yellow garnet, rutile, orthoclase, and blood-red specular hematite. These are called also "piedmontite"-schists, from the name of the manganese-epidote.

GARNET GROUP.

GARNET ROCK, Garnetyte (Dana).

A crystalline-granular aggregate of predominant garnet with an amphibole, augite, epidote, quartz, and magnetite; variously colored.

Silica 44.85; Gr. 3.3–3.54.

It is a rare rock, and occurs in a few irregular beds and lenticular masses in mica-schist and gneiss, and is found in Bohemia, Saxony, Silesia, Tyrol, France, the Urals, Belgium, Canada, and Nevada. With the failure of garnet this becomes amphibolite. In addition to the above minerals there are also found with garnet in smaller proportions and less frequently micas, iron ores, serpentine, apatite, olivine, vesuvianite, calcite, pyrite, and now and then feldspar. Zirkel notes the infrequency of the latter as peculiar. Owing to the great variety of its mixtures the color varies widely. Sometimes the brown or yellowish garnet (aplombe) predominates, so that the rock consists almost wholly of that mineral. It is usually of that color, buff, or greenish white; tough; fine-grained. The stone of that color from Viel Salm, Belgium, forms the best oil-stone in the world. It is there a spessartite (manganese-garnet). At Orford, Canada, a white lime-alumina-garnet (grossularite) forms with a little

serpentine a whitish rock. At St. François, Canada, the same garnet forms with an almost equal proportion of pyroxene a yellowish white to greenish white rock. At Hohen Waid in the Odenwald a beautiful brown garnet forms a rock with quartz, calcite, actinolite, and epidote. At Big Cottonwood Cañon, Utah, a similar rock is formed of brown garnet, quartz, (*m*) epidote, and folia of iron.

ECLOGITE (Haüy).

A coarse- to fine-grained (seldom compact) crystalline-granular aggregate of grass-green omphacite (or diopside) and red garnet with frequent blue cyanite and white mica. The first occurs as a crystalline matrix, usually slaty or fibrous, in which the garnets appear as phenocrysts.

Silica 45–57; Gr. 3.20–3.50.

This occurs in quite extensive lenticular beds in gneiss, granulite, serpentine, and mica-schist, and is found in the Erzgebirge, Fichtelgebirge, Austria, Baden, Scotland, the western Alps, Norway, Sweden, Servia, the island of Syra, Japan, the Orange Free State, at Cape Horn, and a somewhat similar rock is found in the Sierra Nevadas. Omphacite is found in short, thin leek-green or grass-green prisms, which are sometimes serpentinized. The garnet is almandite with variations in the proportions of the ferrous and ferric oxides. It occurs in rounded phenocrysts. Cyanite is usually (*M*); sometimes only (*m*); frequently so predominant that it forms the following variety. Quartz is generally allotriomorphic, and sometimes as large as peas. Black hornblende is usually present, and sometimes exceeds the omphacite and garnet, so as to form an *eclogitic amphibolite*. In some varieties grass-green smaragdite appears with omphacite, and alters to chlorite. The silvery mica is muscovite. Biotite now and then occurs. Zoisite, rutile, apa-

tite, magnetite, pyrite, pyrrhotite, and zircon also occur quite predominantly. This rock is a hard and dense mixture that resists weathering better than its surroundings, and projects from them in prominent knolls.

(*a*) *Cyanite Rock* is a variety of the above where cyanite is predominant. It consists of an aggregate of cyanite and white mica, and also occurs as an offshoot of mica-schist. As the latter it is common in the Green Mountains of Vermont. The cyanite is of varying color, from fine blue to white, and usually occurs in long, flat, bladed crystals, and so predominant that the rock is almost entirely composed of it. As accessories occur garnet, calcite, and occasionally tourmaline.

KINZIGITE (Fischer).

A crystalline-granular schistose aggregate of garnet, biotite, and oligoclase; coarse to compact. A garnet-gneiss.

Silica 44.53; Gr. 3.

This occurs associated with gneiss and crystalline schists in the Black Forest (where it was first noted at the Kinzig), the Odenwald, and in Italy. The first is coarse-schistose, and the ingredients of large size. Oligoclase is white and grayish green, and frequently half an inch in size. It is sometimes accompanied by orthoclase and microcline. Garnet is sometimes as large as peas. Biotite is black, and when quartz appears it forms a garnetiferous biotite-gneiss. Quartz is not common, and occurs in grains and flat lenticules. As accessories occur graphite, apatite, pyrite, magnetite, iolite, sillimanite, fibrolite, and rutile.

AMPHIBOLE GROUP.

AMPHIBOLITE.

A granular aggregate of dark green to black hornblende with more or less quartz, and sometimes chlorite.

Silica 47–50; Gr. 2.9–3.1.

This occurs in beds and flat lenticular masses with gneiss, mica-schist, and phyllite, and is found in Saxony, Silesia, Japan, New England, Nevada, etc. The hornblende is frequently the sole ingredient. As accessories in addition to those given are biotite, orthoclase, plagioclase, garnet, pyroxene, zoisite, and iron ores. These tend to form variations from the schistose variety, and from hornblende-gneiss. In amphibolite there is no tendency to foliation, and the ingredients are arranged irregularly throughout the mass.

Feldspar-amphibolite, Plagioclase-amphibolite, is a variety with considerable plagioclase (and some orthoclase), so that it forms a *meta*-diorite (Dana). It is not common without foliation. Other varieties noted by different authorities are *quartz*-, *epidote*-, *garnet*-, and *calcite*-amphibolite. The last has been already described under its original name, *hemithrène.*

HORNBLENDE-SCHIST.

A granular and schistose aggregate of the above minerals with similar silica and specific gravity.

This is a more widespread rock than the former, as it is associated with schists and partakes of their foliation. It is common in western New England, and the garnetiferous variety of the region running north and south along the Connecticut River between Norwich, Vt., and Hanover, N. H., has been well known for many years as furnishing transparent garnet fit for jewelry. Coarse garnets much fissured are found as large as filberts, but with bright red-

dish brown color. The garnetiferous mica-schist of the Green Mountains frequently contains a considerable amount of calcite intimately mixed with it, so that the rock weathers to a rough surface, and the imperfect garnets in spheroids of the size of French peas, or smaller, project, to give the rock a pitted appearance. Other accessories are epidote, biotite, scapolite, and zoisite, as well as those named above. In some cases the quartz and hornblende are aggregated in flakes or patches, so that the rock has a beautifully mottled appearance. The appearance of feldspar forms a transition to hornblende-gneiss. The hornblende-granulite of the South Mountain in eastern Pennsylvania abounds in segregations of this rock with predominant hornblende, and also intercalated masses of hornblende-gneiss. In the Lake Superior region and in the Alps are dikes of diabase altered to this rock by squeezing, and in Calaveras County, Cal., olivine extrusives have been altered in a similar manner to form *talc*-amphibole-schist. Much oligoclase forms *diorite*-schist.

ACTINOLITE-SCHIST.

A schistose aggregate of actinolite, either alone or with other minerals.

Silica 52–55; Gr. 2.95–3.05.

This occurs like hornblende-schist, and is found in the Fichtelgebirge, the Alps, Italy, and along the Green Mountains. The accessories are generally subdominant to actinolite. They are quartz, feldspar, epidote, garnet, biotite, muscovite, chlorite, monoclinic pyroxene, rhombic hornblende, zoisite, olivine, the iron ores, zircon, and pyrite. *Ollenite* is an *epidote*-actinolite-schist that forms at Monte Rosa a large mass, which varies from schistose to compact.

GLAUCOPHANE-SCHIST, Glaucophanyte (Dana).

A schistose aggregate of glaucophane with accessory epidote and muscovite.

Silica 55–57; Gr. 3.

This occurs in thin lenticules with other schists, and is found in the island of Syra, Switzerland, Piedmont, New South Wales, Bretagne, and California. The glaucophane is in blue acicular crystals with parallel arrangement, so that the mineral has been taken for cyanite. As accessories occur green mica, hornblende, zoisite, quartz, plagioclase, arfvedsonite, rutile, chlorite, and iron ores. A fourchite-sandstone contact near San Francisco, Cal., formed glaucophane-schist.

Epidote-glaucophane-schist is a variety where epidote is predominant. It is found in Switzerland, Piedmont, Croatia, Spain, Greece, and in Asia Minor. Predominant epidote forms glaucophane-epidote-schist.

(NOTE on Amphibole-schists. These are thought by many authorities to have been basic intrusions in the rocks where they are found, and that they have been altered with those rocks to their present state. It may also be noted that in some localities garnet, when finely crystalline, is in trapezohedra rather than dodecahedra.

GREEN SCHIST (Kalkowsky).

A green, grayish green, to greenish black schistose aggregate of quartz and feldspar in varying proportions, with changeable amounts of hornblende, epidote, and chlorite.

This is held by many authorities to be a squeezed diabase. It is found in regions of orogenic movements with phyllite, and sometimes in considerable masses, and is found in the Alps, Silesia, Saxony, Lake Superior, etc. Feldspar

and quartz are the predominant minerals, and form a closely intercrystalline background for the other minerals. The hornblende is light green, greenish blue, and blue, and forms long thin prisms. Epidote is usually a secondary form of hornblende and chlorite. With these occur black augite (sometimes altered to viridite and epidote), calcite, and the ores.

(*a*) *Prasinite* (Kalkowsky) is a similar aggregate of hornblende, epidote, and chlorite of intensely green color, whence the name.

(*b*) *Amphibole-adinole*-schist is a granular to compact felsitic rock like adinole, with a light green to greenish gray color and schistose structure, from Saxony. It is Credner's "hornschiefer." The composition is (*m*) generally, as it is seldom that it is coarse-grained enough to distinguish the ingredients without a strong lens. It is formed of quartz, plagioclase, hornblende, epidote, and magnetite.

PYROXENE GROUP

PYROXENE ROCK.

A granular to compact aggregate of predominant pyroxene without schistose structure, with or without accessories. Silica and specific gravity are as in the mineral group, with variations on both sides.

This occurs with the crystalline schists with changeable character (from variation in the predominant mineral). It never plays as large a part as the corresponding amphibole rock. The varieties are:

(*a*) *Enstatite* Rock. From Bavaria, the Transvaal, and in Delaware and Lancaster counties, Pa. As accessories are magnetite, picotite, olivine, diopside, magnesite, and monoclinic pyroxene. Silica 53–55; Gr. 3.22.

(*b*) *Sagvandite* (Pettersen) is a similar rock from Norway composed of enstatite and magnesite. Silica 55 ; Gr. 3.22.

(*c*) *Diallage-hypersthene* Rock is a fine-grained aggregate from Madagascar.

(*d*) *Augite* Rock forms a granular green and yellow aggregate in the mica-schist of western Massachusetts. It occurs also in Scandinavia and Canada.

(*e*) *Malacolite* Rock forms a white granular and almost compact rock, with splintery to earthy fracture, in a bed in the granular limestone of the Riesengebirge and in Sweden. This is the "pyroxenite" of Coquand. It affords silica 55.

(*f*) *Omphacite* Rock, in large irregular grains, with sporadic grains of olivine and rutile, is found in the Sierra Guadarrama.

(*g*) *Diallage* Rock is a light-green, compact aggregate of diallage, with columnar jointing, from Cyprus, where it is associated with gabbro and serpentine. The diallage is visible with a lens, and is associated with talc, serpentine, and tremolite.

(*h*) *Zoisite*-diallage Rock, from the peninsula of Chalcidice, is an aggregate of dark-colored diallage and white lustrous grains of zoisite. As accessories are a talcose mineral and a monoclinic feldspar. It forms a beautiful rock with coarse granitic structure. The diallage is somewhat altered to green fibrous hornblende.

PYROXENE-SCHIST.

A similar aggregate to pyroxene rock with a schistose structure.

This is somewhat more rare than the pyroxene rock, as the alterations that produce foliation generally alter the rock to hornblende, so that the altered states are found under the amphibole-schists. The silica and specific gravity are as above given. The varieties noted are:

(*a*) *Augite*-schist is a fine-grained schistose aggregate of pale or dark green augite, with sometimes quartz, plagioclase, magnetite, and chlorite, of rare occurrence in the crystalline schists. In some cases they are compact, soft, and readily scratched with the finger-nail. They are so compact that only augite can be noted with a lens. Much plagioclase forms diabase-schist.

(*b*) *Glaucophane*-augite-schist, which varies between diallage and omphacite in its augite content is reported from the island of Syra.

(*c*) *Vesuvianite*-augite-schist is reported from Elster as a thick-banded dirty green or dirty white rock, in lenticules in gneiss, composed of quartz, garnet, and augite, with vesuvianite, plagioclase, apatite, titanite, and pyrite. Generally (*m*).

(*d*) *Egeran*-schist, Vesuvianite-schist, is a schistose aggregate of vesuvianite, augite, tremolite, and quartz. This occurs near Eger, Bohemia, and was first thought to be eclogite. It consists of predominant vesuvianite which obtained its name "egeran" from this locality, where this rock lies in an isolated mass in granite.

ERLAN (Breithaupt).

A crystalline-granular aggregate of almost colorless pyroxene in irregular grains or fibers, with colorless and limpid feldspar, vesuvianite (*m*), quartz, epidote, rutile, titanite, biotite, and muscovite.

Silica 53.16; Gr. 3.–3.1.

This occurs in beds in gneiss, and is found at Erla (whence the name) near the Schwarzenberg. It is usually a compact felsitic mass with light greenish gray color, appearance like saussurite, and fine-splintery fracture. It was thought by Breithaupt to be of an entirely different composition.

OLIVINE GROUP.

OLIVINE ROCK.

A yellowish green to dark green aggregate of granular olivine irregularly arranged, and with or without accessories, but without foliation.

Silica 29–41; Gr. 2.7–3.3.

This occurs in many varieties interlaminated with gneiss, mica-schist, hornblende-schist, talc-schist, granulite, etc. It is a rare combination and usually altered to serpentine. The bands and masses are irregular and of subordinate extent, and, as stated by Geikie, were "probably eruptive masses contemporaneous with or subsequent to the surrounding gneisses and schists." Olivine rarely occurs alone, but is combined with one of the pyroxenes. It alters to serpentine and talc. The varieties are:

(*a*) *Enstatite*-olivine Rock, with diopside, green clinochlore, and magnetite, in a bed in the Fichtelgebirge with hornblende-gneiss. It alters to talc-schist. It is also found in Austria and Sweden.

(*b*) *Bronzite*-olivine Rock, from Austria, between diorite-schist and biotite-gneiss, consisting of olivine and actinolite in which the bronzite occurs as phenocrysts. Spinel, serpentine, magnetite, and chlorite also occur.

(*c*) *Amphibole*-olivine Rock, from Himberg, Austria, with olivine forming one third of the mass, the rest being actinolite, hypersthene, dark green spinel, clinochlore, and talc. The weathered crust shows amphibole and anthophyllite. It occurs also in Sweden.

(*d*) *Garnet*-olivine Rock, in granulite of the Kampthal, Austria, is composed of olivine, picotite, pyrope, bronzite, hornblende, and scanty diallage in a coarse mixture.

(*e*) *Chromite*-olivine Rock. This is like *dunite*, but carries actinolite, pearly mica, sporadic diopside, and pyrrhotite.

It is found at the Eulengebirge in Silesia, where it forms a dark green lenticule, thirty feet long, in amphibolite. A serpentinized variety is found in Steiermark, and in Norway (in quartzite and mica-schist) is a similar greenish fine-grained aggregate of light olivine, colorless pyroxene, mica, and chromite.

OLIVINE-SCHIST.

A schistose aggregate of predominant olivine, fresh or serpentinized, and with or without accessories. Silica and specific gravity as above.

This occurs to a slightly less extent than the "rock," as the imposition of foliation induces changes to serpentine or talc. There is not so much of a tendency towards predominant minerals associated with olivine as in the last variety. As accessories are smaragdite in prisms, light brown enstatite, chromite, bronzite prisms, black hornblende, acicular tremolite, augite, gold, garnet, talc, chlorite, and magnetite. It is found in Sweden, Greenland, Africa, and in a widely developed zone between the Blue Ridge and the Great Smoky mountains in North Carolina. At the last locality the olivine is fresh and oil-green, and varies from a distinct schist to a rock with slight foliation.

EULYSITE (Erdmann).

A thin-plated aggregate of fayalite, omphacite, and brownish red garnet, with some apatite and magnetite, and (sporadically) smaragdite-like hornblende and mispickel.

This occurs near Tunaberg, Sweden, in a thin lenticular bed in granulite (or gneiss) about 30 feet thick and 350 to 500 feet long.

MINERALS AS ROCKS.

Under this division it is proposed to discuss the iron ores, serpentine, kaolin, bauxite, magnesite, barite, the iron sulphurets, and sulphur. Some of these might have been included under the previous groups if their origin had been a single one, but as they have been formed in a number of ways, they must be placed by themselves, rather than split among the various classes according to the forces that produced each portion. The others are simple minerals and only of local occurrence, so that their bulk is inconsiderable in comparison with the simple minerals noted in the previous pages. They will be described without further discussion, and those of similar composition will be grouped together.

THE IRON GROUP.

LIMONITE (Beudant, not of Hausmann, as the latter was for bog ore only), Brown Hematite (Jameson), Brauneisenstein (Ullman, not of Werner nor Hausmann, as they included more than this rock), Bog-iron ore (Kirwan).

A compact, earthy, porous, fibrous, scaly, oölitic aggregate of hydrated sesquioxide of iron; yellowish (through brown) to black; yellowish brown streak; with accessory manganese, clay, and silica.

Iron 59.89; water 14.44; H. 1–5.5; Gr. 3.4–3.95.

It occurs at the bottom of marshes (whence the name), ponds, and lakes, where it has settled from chemical precipi-

tation or the action of organisms on the solutions in which it is held; as a matrix of the lower layers of porous strata resting against impervious ones; as mixed with drift when aggregated from old surfaces by glacial action; as replacing silica in chert or limestone (dolomite) in beds and oölitic aggregations; as alterations of hematite or siderite; as rustings and weatherings of ferruginous minerals (magnetite, pyritiferous aggregates, black bisilicates, etc.), or leachings from ferruginous soils and clays. It is thus aggregated with clay, sand, gravel, and other impurities in more or less compact forms. It forms purer concretions of varying form from shot and pea sizes to aggregates weighing several hundredweight. It is always forming and quite rapidly, as the clays from limonite washings that have been emponded form strata of considerable depth, which have along their lower layers incipient aggregations of a soft nature, and in several cases the writer has found shelly concretions about discarded track-spikes that have lain in moist places—the spike being reduced to a skeleton of the impurities in the iron. The wooden boxes leading water from coal mines in a short time are lined with a layer of limonite, and whatever impurities may have been in suspension, as a compact and hard rock. The places where the aggregations take place are generally hollows in the surface rocks, or in beds where replacement is in progress. In some cases the cavities are caverns hollowed by subterranean solutions whose roofs have fallen in or been removed by glacial action. It is found in surface hollows mixed with clay, drift, etc., along the Archæan area of the Atlantic border of the United States; as cement for sands, etc., in Lehigh, Northampton, Columbia, and (extensively) Center counties, Pa.; as replacing silica and calcite in beds from Virginia to Georgia, Texas, Vermont, and elsewhere. These can be divided into two general varieties:

(*a*) *Bedded*, where the aggregates are replacements or concretions in definite beds. Here the impurities are those of the original bed, and the iron is more generally disseminated through the mass than assembled at definite points. Here also are placed the fillings of veins, cracks, etc., in other rocks.

(*b*) *Loose*, where the ore is in aggregates distributed through surface accumulations, and can be readily worked by pick and shovel.

As far as general appearance of the individual particles is concerned, there is little difference in appearance between these two divisions, and in each are found particles from shot sizes up to many feet in diameter which may be clayey, soft, and impure, showing the lighter colors noted above, or comparatively pure, dark-colored, and hard. The shapes may also vary from massive to reniform, stalactitic, oölitic, scaly, pisolitic, concretionary (solid or hollow),—in the last case called "ore-pots,"—or the ore may be a coloration of clay, sand, etc., either loose or hard; if the former, it is *yellow ocher*.

RED HEMATITE, Specular Iron.

A compact, earthy, fibrous, scaly, oölitic, and sometimes crystalline aggregate of anhydrous sesquioxide of iron; red to black; streak red; with accessory manganese, silica, and clay; sometimes magnetic, and magnetipolar.

Iron 70; H. 2–6.5; Gr. 4.5–5.2.

This occurs like limonite, but under conditions that favored the formation of anhydrous sesquioxide, such as the deposition of iron oxide in heated waters, the replacement of silica and calcite in beds in hot climates; and, unlike limonite, it may have had an eruptive origin It is found in

beds and lenticular masses in the crystalline schists, and frequently with the crystal (specular) form. It also is found as original or replacement formations in oölitic aggregations, as in the beds of the Clinton formation from New York to Alabama, and in Wisconsin, Illinois, and Kentucky. In many cases this is a replacement, as the fragments of shells are turned to ore, and in the interiors of many of the unchanged ones are specular crystals from the intruding solutions. The extensive beds of the Penokee-Gogebic region are also replacements; the immense beds of the Marquette-Menominee region are thought by some to be eruptive, and the Mesabi beds to be precipitates from a heated ocean—as are the clay ironstones, which are mixtures with clay. There are decided varieties of this rock, as follows:

(*a*) *Red Hematite.* This is the common kind, and is compact, earthy, fibrous, and oölitic. It breaks with an earthy to silky luster.

(*b*) *Micaceous* Hematite. This is a variety in thin folia. In some cases it is interbedded with chlorite schist, as in Hungary. At the Republic mine in Michigan the immense bed is formed of a fine micaceous aggregate with metallic luster and somewhat fissile structure.

(*c*) *Specular* Hematite. This occurs in crystalline aggregates. The island of Elba affords fine examples. It is also found at Pilot Knob, Mo., in the Lake Superior region, New York, and Canada.

As an example of parallel beds of varying ores the Lynchburg region of Virginia is remarkable, as there one finds limonite, red hematite, and magnetite in parallel contorted beds between chlorite-schists, limestones, and sandstones. When the inclosing rocks are both limestone, the bed is limonite; when limestone on one side and sandstone or schist on the other, red hematite; when sandstone and

schist, magnetite. The following varieties are due to admixtures with other minerals:

(*d*) *Siliceous* Hematite. This is a replacement of silica by hematite to form a jasper, thence a jaspery hematite, thence a hematite. All variations can be found in the many workings of Center County, Pa.

(*e*) *Black* Hematite is a manganiferous variety with a black color and streak.

(*f*) *Menaccanite*, Ilmenite, Titaniferous Iron Ore, occurs in beds or veins in diorite at Krageröe, Norway, and in masses at Bay St. Paul, Canada, in syenite. It also occurs as sands, and is called *iserine*.

MAGNETITE.

A granular, compact, and schistose aggregate of a compound of protoxide and sesquioxide of iron; black color and streak; metallic luster; magnetic and magnetipolar.

Iron 72 41; H. 5.5–6.5; Gr. 4.9–5.2.

This occurs in beds and lenticular masses of great size in gneiss, mica-schist, chlorite-schist, hornblende-schist, and granular limestone, and is found in the Archæan formations of the world, and especially in Scandinavia, the Urals, eastern North America, and the Lake Superior region. Its origin is either eruptive or metamorphic. As the former it occurs in gabbro regions, and in Rhode Island is a titaniferous magnetite eruptive (cumberlandite). It sometimes seems to be a metamorphosed limonite; in north Wales it is a metamorphic replacement of oölite. Among large masses is the iron mountain of Gellivara in Lulea-Lappmark which is over 500 feet high, 1½ miles wide, and 3 miles long. The accessories are numerous, as would become a metamorphic rock, and are hematite, chromite, chlorite,

titanite, pyrite, chalcopyrite, quartz, apatite, hornblende, augite, garnet, feldspar, etc. The varieties are:

(*a*) *Catawbirite* (Lieber). From South Carolina, where it occurs in great abundance. It is an intimate aggregate of magnetite and talc.

(*b*) *Chromic* Magnetite, where chromite is the sole accessory, and is predominant in the mixture.

(*c*) *Garnetiferous* Magnetite. This occurs near garnet rock, and passes into it.

SIDERITE (Haidinger), Spathic Iron.

A granular to compact aggregate of carbonate of the protoxide of iron; yellowish white, gray, or yellowish brown; streak white; darkens to brown or black on exposure to the air; effervesces with acids.

Iron 48.22; H. 1–4.5; Gr. 2.5–3.9.

This occurs in beds and masses of varying dimensions, but not so large as in the ores already described, in gneiss and the crystalline schists, and as beds (with clay) in recent formations also; in veins in the oldest rocks, and in the Erzberg in Styria forms a mountain 2700 feet high. As black-band and clay ironstone it occurs in beds in various formations. As spathic ore it is found at Roxbury, Conn.; as clay ironstone, in the Carbonic of the Appalachian area, and as a bed extending under Chesapeake Bay. As black-band it is found in the coal measures of the United States — though not worked, owing to the abundance of better ores. As varieties are:

(*a*) *Sphærosiderite*, Clay Ironstone, is a dull brown to black compact form of siderite, with a variable mixture of clay and some organic matter. It occurs in the Carbonic and other formations in the form of nodules gathered about some object (pebble, leaf, fossil), or as beds interstratified with shales and coals.

(*b*) *Black-band.* A compact and frequently siliceous clay ironstone rendered black by a large proportion of carbon, and with so much of it that it will inflame in heaps without admixture with coal.

FRANKLINITE (Berthier).

A massive, coarse- to fine-granular and compact aggregate of protoxides of iron, zinc, and manganese, compounded with sesquioxides of iron and manganese; iron-black; streak dark reddish brown; luster metallic; acts slightly on the magnet.

Iron 45–48; zinc 9–20; manganese 8–12; H. 5.5–6.5; Gr. 5.07.

This may be called a manganese-zinc-magnetite. It occurs at Franklin and Sterling Hill, N. J., where it forms large beds in granular limestone, and is associated with massive zincite and willemite. This is its only occurrence as a rock.

SERPENTINE ("Ophites," Pliny).

A massive, fine-granular to cryptocrystalline and compact rock, sometimes slaty, soft, with greasy feel; dark green to brown; usually with accessory minerals.

Gr. 2.5–2.7; H. 2.5–5.5.

This occurs in many ways, as already described in the foregoing pages, and is the alteration product from many minerals. The varieties with calcite have been noted. It frequently is porphyritic from phenocrysts of pyrope, and often slaty. The accessories that form varieties are olivine, amphibole, pyroxene, garnet, chlorite, talc, and the iron ores; less frequently quartz, and opal. As variations in texture and structure are: (massive) retinalite, porcellophite, and bowenite; (lamellar) antigorite, from

Piedmont; williamsite, from Texas, Pa.; (foliated) marmolite, from Hoboken, N. J., Blandford, Mass.; thermophyllite, from Hopansuo, Finland; (fibrous) chrysotile, picrolite — both abundant. Admixture with opal forms *silicophite* (Schrauf); with garnet, *garnet*-serpentine; with bronzite, *bronzite*-serpentine, etc. It joints irregularly (exceptionally it is columnar, frequently tabular). It is most frequently found in irregular and subordinate beds between crystalline schists, and also forms the necks of altered eruptives. It occurs massive and in workable quantities in New England and along the Atlantic States.

BARITE, Barytes, Heavy Spar.

Sulphate of barium; Gr. 4.3–4.7; H. 2.5–3.5; white to black — usually white, gray, or blue (the last two being transparent).

It occurs as a gangue in metal-bearing veins throughout the world, and in veins and pockets in limestone. It is found in bowlders and nodules in clay in Virginia, between slate and limestone, and in surface clay in Missouri. The supply in the United States comes from the last two States, though small amounts are found in North Carolina, Illinois, and New England.

MAGNESITE (Brongniart).

Carbonate of magnesia; Gr. 3–3.2; H. 3.5–4.5; white to brown (according to the amount of iron).

It occurs associated with serpentine, talc-schist, and other magnesian rocks, and is found at Veitsch (Styria), Austria; near Frankenstein (Silesia), Prussia; Mantoudi (Eubœa), Greece; and Child's Valley, Cal. The Austrian deposits are beds conformable to Silurian strata; those of Greece are in large veins in serpentine. Magnesite has also been reported from Bolton, Canada.

KAOLIN, Porcelain Clay.

Hydrous silicate of alumina; Gr. 2.4–2.63; H. 1–2.5; white when pure, but colored variously by impurities.

This occurs as the alteration by weathering of aluminous minerals, especially feldspars of granite and gneissoid rocks and porphyries. Where weathering has taken place for a long time, without erosion, there remains a large deposit of kaolin. It is found in the Carbonic measures of the Appalachian region, and forms extensive beds in the Tertiary formation near Richmond, Va. A variety at Lawrence County, Ind., and elsewhere through that State, with a great amount of water, is called *indianaite*. It is found at Brandon, Vt.; in the Cretaceous and Quaternary of New Jersey; in Delaware, Maryland, Missouri, Oregon, and California.

BAUXITE.

Hydrated sesquioxide of alumina with accessory silica and sesquioxide of iron; Gr. 2.55; H. 1–3; whitish, yellowish, brown, red, and black, and always more or less stained with iron, manganese, and other minerals.

This occurs as sediments (in Europe) alternating with sandstones, limestones, and clays; in pockets and cavities in limestone, and in concretionary grains scattered through the limestones. It is generally oölitic or concretionary. The geological formations where it is found are Trias, Jurassic, and Miocene-Tertiary. It occurs in the United States in residual clays and irregular and ill-defined deposits, which may be alteration products of underlying limestones, as in Europe. The geological horizons of the deposits are Lower Silurian and Tertiary. It is found in Georgia, Alabama, Tennessee, and abundantly in Arkansas, where it is said to be inexhaustible. It is a source of aluminium.

PYRITES.

Sulphides of iron of varying compositions; Gr. 4.4–5.2; H. 3.5–6.5; brass-yellow; streak grayish black, greenish black. Under this title are included pyrite, pyrrhotite, and marcasite.

These occur disseminated in small quantities through the rocks of all ages, and often in large beds of such size as to be called masses. They are found along the eastern slope of the Appalachians from Maine to eastern Alabama. Mines have been worked at Capelton, Canada, Milan, N. H., Stafford, Vt., Rowe, Mass., and Tolersville, Louisa County, Va. The first and last are the only ones at date affording much of an output. These deposits, though large, are not to be compared with the Rio Tinto deposits that stretch from Spain into Portugal in two vast beds or veins in metamorphic schists. The southern vein is 300–400 feet wide, and at least 2500 feet long; the northern, 1300–1600 feet wide, and 6000 feet long. At Goslar in the Harz Mountains is a vein of cupriferous pyrites which is 350 by 1800 feet. At Fahlun, Sweden, is a mass of similar composition in Archæan gneiss and schists. At Agordo, Tyrol, is a mass in talc-schist and clay-slate varying in width from 12 to 250 feet. Large desits also occur at Domokos, Transylvania, and Schmöllnitz, Hungary.

SULPHUR.

Pure sulphur; Gr. 2.072; H. 1.5–2.5; color and streak sulphur-yellow.

This occurs about active volcanoes or associated with beds of gypsum. We can therefore divide the deposits under two types:

(*a*) The *solfatara* type, where the mineral is deposited directly from volcanic exhalations (H_2S and SO_2) in cracks

in the lava and tuffs, or in the clay resulting from their decomposition.

(*b*) The *gypsum* type, where bituminous matter acts on gypsum and reduces it to calcium sulphide and water. The former, being soluble, is affected bythe air, while in solution, to form calcium carbonate and polysulphide of calcium, and the latter breaks up and deposits the excess of sulphur.

The first type is found in Italy, Japan, southern Utah, and is extensively worked in the two last -- the first being somewhat exhausted. The second type is found associated with gypsum in Sicily, France, Spain, northeastern Italy, Greece, and Poland in Miocene-Tertiary formations. Jurassic beds occur in the Caucasus, and Quaternary deposits in southwestern Louisiana.

SCHEME FOR DETERMINING THE PRINCIPAL ROCKS.

The specimen will fall under one of the four grand divisions, according to its TEXTURE.

(A) *Clastic, fragmental, or sedimentary* (part). p. 382.

(B) *Compact, dull, or subvitreous.* p. 384.

(C) *Compact, vitreous, or resinous.* p. 386.

(D) *Crystalline-granular.* p. 387.

It will then be tested to see under which of the following heads it falls:

I. Untouched or slightly touched by acids.

II. Partly attacked by acids.

III. Completely soluble without effervescence.

IV. Soluble with more or less effervescence.

V. Burns more or less readily; detonates with KNO_3.

Having determined under which of the above it falls, it will then be examined regarding its STRUCTURE, whether it be (*a*) Massive; (*b*) Stratified or schistose; (*c*) Porphyritic; (*d*) Vesicular or amygdaloidal.

Turning to the following pages, a list of rocks will be found that belong to each group indicated, and the species can be determined by the characteristics there given.

(*A*) CLASTIC OR FRAGMENTAL ROCKS.

I. UNTOUCHED BY ACIDS.

(a) *Massive or stratified.*

Infusible and insoluble in alkaline solutions.

Conglomerates and breccias of quartz, jasper, the granites, syenites, etc.

Sand, gravel, and shingle.

Sandstone, grit, and arkose.

Soluble in alkaline solutions.

Conglomerates and breccias of opal.

Tripoli and tripoli-slate.

Fusible.

Conglomerates and breccias of felsite, trachyte, pitchstone, rhyolite, the mica-traps, porphyrites, etc.

II. PARTIALLY ATTACKED BY ACIDS.

(a) *Massive.*

Infusible or slightly fusible.

Clay and loam, claystone, shale, clay-slate, and the acid tuffs.

Fusible readily.

Conglomerates and breccias of dolerite, basalt, phonolite, gabbro, etc.

The various basic tuffs.

III. COMPLETELY SOLUBLE IN ACIDS WITHOUT EFFERVESCENCE.

(a) *Massive or stratified.*

Give water.

Gypsum, and the hydrated iron and manganese ores.

Without water.

Anhydrite, and the anhydrous iron and manganese ores, except siderite.

IV. MORE OR LESS SOLUBLE IN ACIDS WITH EFFERVESCENCE.

(a) *Massive or stratified.*

The limestones and dolomites, siderite, marl, travertine, and tufa. Conglomerates and breccias of the above, and bone-breccia.

V. BURN MORE OR LESS READILY.

(a) *Massive or schistose.*

The carbonic and hydrocarbonic rocks.

(*B*) COMPACT; DULL OR WITH FEEBLE LUSTER.

I. UNTOUCHED BY ACIDS.

(a) *Massive.*

Infusible; insoluble in potash lye; density 2.6.

Chalcedony, jasper, Lydian stone, and other cryptocrystalline varieties of quartz.

Density 2.9 or above.

Euphotide, the variety containing Saussure's jade from Monte Rosa.

Soluble in potash lye.

Semi-opal, siliceous sinter, and other cryptocrystalline forms of opal.

Fusible.

Compact mass and hardness 6. Felsite; fine-grained or microcrystalline mass. Leptinolite, Adinole, Porphyroid. The compact states of the porphyrites.

(b) *Stratified or schistose.*

Fusible.

Porphyritic. Slaty Porphyry; not porphyritic. Hälleflinta.

Infusible.

Novaculite.

(c) *Porphyritic.*

With quartz. Quartz-porphyry; with quartz, feldspar, and mica. Granite-porphyry; without quartz. Feldspar, mica, and hornblende-porphyrite.

II. PARTIALLY ATTACKED BY ACIDS.

(a) *Massive, schistose, porphyritic, and amygdaloidal.*

Infusible or slightly fusible.

Gray mass with crystals of leucite and augite. Leucite-phonolite, and compact forms of leucite-bearing rocks.

Reddish or grayish porous mass, with bluish crystals of haüyne. Haüynophyre.

Easily fusible.

Color green rather than black, decolorized by HCl. Augite porphyrite, Aphanite.

Mass like the above with grains, globules, or pustules of a hardness of 6, fusible. Variolite.

Bluish or grayish black mass, usually with olivine, seldom containing quartz, more commonly calcite or zeolites, in amygdaloidal cavities, fuses to black globule, density generally 3. Basalt.

Compact mass, black on fresh fracture, weathers reddish, fusible to bottle-green globule, never with olivine, frequently with quartz in amygdaloids, density generally less than 3. Melaphyre.

Compact, subgreasy mass, smooth fracture, gray color, density 2.6, easily fusible. Nepheline-basalt.

Compact, dull, greenish mass, fusible to white globule, yields water when heated, gelatinizes in HCl, with sanidine in crystals. Phonolite.

III. COMPLETELY SOLUBLE WITHOUT EFFERVESCENCE.

(a) *Massive, stratified, and sometimes porphyritic.*

Give water.

Hardness 1.5–2, give sulphur and lime. Gypsum.

Hardness 3–4, rarely 5, green, red, brown, sometimes is porphyritic from crystals of garnet, blackens before the blowpipe and fuses with difficulty. Serpentine.

Give iron or manganese reaction, density 3.5–4.5. Hydrous ores of iron and manganese.

Give no water.

Give sulphur and lime. Anhydrite.

Give iron or manganese reaction, density 4.5–5.5. Anhydrous ores of iron or manganese.

IV. MORE OR LESS SOLUBLE WITH EFFERVESCENCE.

(a) *Massive and stratified.*

Hardness under 3, *infusible.*

Some limestones, dolomites, and calcareous clay slates.

A mixture of calcite and serpentine. Ophiolite.

(*C*) COMPACT, VITREOUS, OR RESINOUS.

I. UNTOUCHED OR SLIGHTLY TOUCHED BY ACIDS.

(a) *Massive, schistose, and sometimes porphyritic.*

Infusible, soluble in potash lye, never porphyritic. Opal, Siliceous Sinter.

Fusible.

Conchoidal fracture, fusible to a blebby globule. Obsidian.

Pearly luster, splintery fracture, gives water in the open tube, frequently containing round grains. Perlite.

Resinous luster, conchoidal fracture, fuses without intumescence to a white vesicular glass. Pitchstone; with balls of felsite, or crystals or grains of feldspar, and quartz. Pitchstone-porphyry.

Mass porous, perlitic, sometimes slaty, with crystals of sanidine, mica, or quartz. Rhyolite.

(b) *Vesicular, scoriaceous, pumiceous.*

Perlite and obsidian occur in the first two states; when in the third, the rock is called pumice. Dark mass, fusible

to black slaggy globule, heavier than pitchstone, obsidian, or perlite. Hyalomelane.

II. DECOMPOSED BY ACIDS.

(a) *Massive and vesicular.*

Dark mass, fusible to black slaggy globule, heavier than pitchstone, obsidian or perlite. Tachylite.

(*D*) CRYSTALLINE OR CRYSTALLINE-GRANULAR.

I. UNTOUCHED OR SLIGHTLY TOUCHED BY ACIDS.

(a) *Massive, and frequently porphyritic.*

Coarse crystalline-granular or granitoid.

Quartz, orthoclase, and granite, with mica replaced by talc or chlorite. Protogine; by tourmaline. Tourmaline-granite; with tourmaline abundant and flesh-red orthoclase. Luxullian; mica replaced by epidote. Epidote-granite; by iolite. Cordierite-granite; by hornblende. Syenitic Granite.

With the quartz arranged in layers on the cleavage planes of the orthoclase and white mica. Graphic Granite.

Like the last, but more coarse and irregular. Pegmatite.

Quartz and orthoclase. Aplite.

Quartz and zinnwaldite. Greisen.

Orthoclase and hornblende. Syenite.

Oligoclase and hornblende, greenish appearance. Diorite.

Oligoclase, hornblende, and quartz. Quartz-diorite.

Oligoclase, hornblende, quartz, and biotite, fusible. Tonalite.

Oligoclase, orthoclase, hornblende, mica, and quartz. Mica-diorite.

Cyanite and white mica, with garnets, infusible. Cyanite Rock.

Mica, garnet, and iolite. Kinzigite.

Garnet and smaragdite. Eclogite.

Fine crystalline-granular.

Rough mass, containing crystals of sanidine and hornblende, density 2.6, mass fusible to colorless glass or enamel. The Trachyte group.

Grayish mass, containing much magnesian mica in laminæ, infusible or slightly fusible. Minette.

Fusible mass, with much magnesian mica in laminæ and crystals of hornblende, and oligoclase. Kersantite.

Reddish mass, hardness 7, attacked by HCl after long heating, density 3.4–4.3. Garnet Rock.

Diallage and Saussure's jade (compact zoisite) fusible with difficulty, gelatinizes after fusion. Euphotide (in part).

Rough porous mass, gray or black, with crystals of oligoclase and hornblende. Andesite.

Like the above, but pyroxene replacing the hornblende. Pyroxene-andesite.

Grayish, porous, crumbly mass like claystone, oligoclase, hornblende or augite, and dark mica. (Domite from the Puy de Dôme); same composition, undecomposed. Domite.

(b) *Stratified or schistose and frequently porphyritic.*

Contain feldspar.

Orthoclase or oligoclase, quartz and mica. Gneiss; with talc or chlorite replacing mica. Protogine-gneiss; with iolite for mica. Dichroite-gneiss; with hornblende for mica. Syenitic Gneiss.

Plagioclase and hornblende. Diorite-gneiss, Gabbro-gneiss.

Orthoclase and black mica, grayish or brownish mass. Schistose Minette.

Orthoclase and quartz, frequently with garnet and cyanite. Granulite.

Without feldspar and with quartz.

Quartz in crystalline grains. Quartzite, Quartz-schist.

Quartz and a little white mica, in thin sheets, flexible. Itacolumite.

Quartz and much mica. Mica-schist.

Quartz and tourmaline. Tourmaline-schist.

Quartz, tourmaline, and topaz. Topaz Rock.

Quartz, in greater or less amount, and talc. Talc-schist; with pyrophyllite in place of talc, and no quartz. Pyrophyllite-schist.

Quartz and hornblende, sometimes hornblende alone, fusible to black or dark green enamel. Hornblende-schist; an aggregate of actinolite. Actinolite-schist; with glaucophane, Glaucophane-schist; with epidote and glaucophane, either Epidote-glaucophane-schist or the reverse, dependent on which is predominant.

With much argillaceous matter, Argillite; with much argillaceous matter and much mica, quite easily fusible, Phyllite; with ottrelite, Ottrelite-schist; with chiastolite, Chiastolite-schist; with decomposed pyrite, Alum-schist; with carbonaceous matter, Black Chalk.

(c) *Vesicular and amygdaloidal.*

Feldspathic mass, density 2.6, rough, and generally more or less fusible. Vesicular Rhyolites and Trachytes.

II. PARTIALLY ATTACKED BY ACIDS.

(a) *Massive.*

Pyroxene, white or gray labradorite, or oligoclase, and magnetite, sp. gr. 2.9–3, color generally black or gray. When coarse-crystalline, Dolerite; when fine-crystalline, Anamesite.

Augite, labradorite, or oligoclase, viridite, and magnetite, color greenish. Diabase.

Pyroxene and nepheline, greasy luster, sp. gr. 2.6. Nepheline-dolerite.

Pyroxene and leucite, the latter in rounded, indistinct crystals. Leucite-dolerite.

Pyroxene and haüyne with olivine, mica, and leucite; porous; brownish or grayish color. Haüynophyre.

Pyroxene and hornblende with labradorite and oligoclase, frequently some mica; gray or brown; mass fine-crystalline to compact. Trachydolerite.

Diallage and plagioclase; easily fusible; pearly luster. Gabbro.

Diallage, plagioclase, and much dark olivine. Olivine-gabbro.

Plagioclase and hypersthene, or bronzite. Norite.

Hornblende, labradorite, and oligoclase. Labradiorite.

Orthoclase, elæolite, zircon, and hornblende. Elæolite-syenite.

Orthoclase, red elæolite, and hornblende. Foyaite.

Greenish black hornblende and anorthite. Anorthite-diorite; if arranged in concentric crystalline rings, alternating with one another. Orbicular Diorite.

Deep green hornblende, white or gray anorthite, and little quartz. Egeran.

Hypersthene in long black needles, augite, and labradorite. Teschinite.

Pyroxene and anorthite. Eukrite.

Yellow or green chrysolite (decomp. by H_2SO_4; sol. in HCl and chromite). Dunite.

Fine-grained, greenish gray mass with vitreous feldspar (sanidine); weathers with a sharply defined white crust. Phonolite.

(b) *Stratified or schistose.*

Fine-grained, greenish gray mass, showing cleavage sur-

faces of a vitreous feldspar; weathers with sharply defined white crust. Phonolite.

Pyroxene, labradorite, viridite; color greenish. Diabase-schist.

Fine-grained, greenish, hardness 2.5–4. Chlorite-schist.

(c) *Porphyritic.*

States of the rocks described under (a) and (b).

(d) *Vesicular and amygdaloidal.*

The dolerite group, Diabase, Phonolite.

Cavities filled with analcite. Analcimite.

III. COMPLETELY SOLUBLE WITHOUT EFFERVESCENCE.

(a) *Massive.*

The iron and manganese ores.

White, hardness 2.5; completely soluble in H_2SO_4, giving HF. Cryolite.

IV. MORE OR LESS SOLUBLE WITH EFFERVESCENCE.

(a) *Massive.*

The limestones and dolomites, siderite, and travertine.

Greenish felsitic mass with much mica; iron pyrites frequently. Fraidronite.

(b) *Stratified or schistose.*

Quartz, mica, and more or less calcite. Calcareous Mica-schist.

Calcite and mica. Cipolino.

Greenish mass, hardness 5; contains calcite. Kalk-aphanite.

THE ECONOMIC VALUE OF ROCKS.

In the previous pages the different rocks of the earth's crust have been described and their accessories given. The latter are sometimes beneficial and sometimes injurious when we examine the variety from the standpoint of value, and that is the reason why long lists of accessory minerals have been noted, when they made no variation in species, and exerted no influence upon the color or general character. It remains to briefly examine the rocks from another standpoint and to see how they are useful. In this light the majority of them are found to be interesting from their differences, but are either inconsiderable in quantity, or worthless from structural or other defects. The useful rocks that remain are few, and in such quantity that it will pay to assemble the necessary machinery to work them.

The general value of a deposit depends on its amount, the shape in which it is presented, and its distance from market. The last generally disappears with the advent of civilization, and the market comes to the deposit if it be valuable, as the greater portion of the forces tending to civilize the race had their impetus from a desire to secure lasting temples for their divinities, and to fitly adorn them, so that traffic in stones required roads, and the growth of taste inspired arts of adornment. We can describe the savage as the man of the *stone* age, where the spallings of nature were utilized, and the civilized man as the man of *metals*. The second of the above conditions is always an important one, for upon it depends the sizes of the pieces

obtained and their shapes. A bed of first-class granite may be so jointed and fissured that it cannot be gotten out in pieces of any size, and can only furnish smaller material, like Belgian blocks for paving. In the same way the accessory minerals affect the value of mortars, abrasives, fertilizers, lubricants, etc., and injurious ones that cannot readily be removed destroy them entirely; so that the examination of a deposit should not end with a survey that determines its bulk, but should include an analysis of its surface impurities and a study of the same at depths, as weathering may have removed harmful portions; and should further determine the purposes for which it is unfit, as well as those to which it is adapted.

As the principal use of rocks is as materials for construction, those fit for such a purpose will first be considered. They may be utilized as spallings, or in bulk ("dimension stones"). Their value in the latter case depends upon their strength and life, and these vary with the means of consolidation, which are:

1. Intercrystallization of the minerals together without cementing material.

2. Compression of the clastic grains so that they have been forced to fill the inequalities in those adjacent, and thus approach the intercrystallization of the first case.

3. A cementing medium, which may be:

(*a*) Silica.

(*b*) Clay.

(*c*) Calcite.

(*d*) Iron oxides.

The *strength* of a rock depends on its compactness, freedom from a cementing medium, hardness, and position with respect to its bedding planes; so that rocks formed through the first two means are stronger than those formed through the third—if of equal hardness and compactness.

The *life* of a rock varies with the resistance to weathering of its weakest part, so that uniformity of composition is a prime requisite. Conditions that favor weathering are: possessing cements of clay, calcite, and iron oxides; admixtures with pyritous minerals, or whatever will readily seek more stable forms. In fine, the aggregates of the most stable minerals will live longer that unstable ones. The locality in which the rock is to be used must be considered, as this greatly influences the rock value. A porous rock that would readily scale with frost in the latitude of New York City would weather well in Florida and more tropical regions. Evenness of temperature is a prime factor in longevity, and a stone that would spall under the changes of temperature at New York would last well in the even temperature of the Pacific coast from California to Washington. This is the reason why Egyptian monuments have retained their freshness, though exposed to fierce heats; but have scaled through the variations in temperature when removed to this and other climates. Porosity does not enter here, as so dense a rock as the Potsdam quartzite in a few years takes spheroidal shapes through changes in temperature, while the rock is fresh, as shown in recent railroad cuts. We must therefore consider the region in which the rocks are to be used, and the effects of variation in temperature, as well as changes in atmospheric conditions. Under the latter comes the difference in behavior of the magnesian limestone of which the houses of parliament of Great Britain are built. When used to build country seats, it has lasted for years in pure air, but the gas-laden air of London is surely destroying it. The economic value of a rock, therefore, depends on many conditions outside of its composition. The different rocks fit for constructive purposes will now be discussed.

Granite. Under this head will be noted the primary

rocks and similar crystalline schists. The most durable are those with fine grain, with small amounts of the black bisilicates, not too much feldspar, and compact and non-porous structure. The admixture with too many accessories allows too much variation in expansion among the ingredients, and consequent strain in the mass; or, with pyritous minerals, carries weathering to its interior; while porous feldspathic varieties absorb moisture and readily kaolinize. The *beauty* of a granite is in its uniformity of grain and color; so that variations in the first, and inclusions of foreign rocks (more or less resolved), such as knots of mica-schist, etc., lower the value. Gneiss is often as good as granite, and generally does not absorb as much heat, so that it cannot be subjected to as sudden strains by changes in temperature, but it is never as uniform in color. Diabase and diorite cannot be compared with the above, as they readily weather; and basalt is inferior from the same cause, as well as from its being fine-jointed, so that it cannot be obtained in large pieces, and its brittleness forbids its ready dressing. For want of a better stone trachyte is sometimes used; but in competition with granite (under which syenite is included) and gneiss the porous extrusives are of little value in climates with severe frosts, but can be used in the tropics. The exceptions to this statement are the phonolites which have been rendered slaty, and the devitrified basalts and rhyolites which have been altered and transformed to slates, but these are not used in masses, so that the above rule holds good.

Sandstone. The nearer this rock comes to the second condition above given, and is free from cementing media, the better it is for building purposes. A small amount of clay will not lower the strength of a fine-grained variety; but if coarse-grained and porous it will absorb water and cause the rock to swell. Some rather fine-porous stones

will be unfit for immediate use if quarried at or near water level, as they will be full of moisture. This will make a damp wall on the inside, and flake under frost on the outside; so that the stone should be well seasoned before being dressed and used. Calcareous cements in sandstone will invariably and speedily dissolve and allow the rock to crumble. The best varieties are those purely siliceous, of fine grain, and free from pores, cements, and unstable accessories.

Limestone. This is generally not as fit for exteriors as sandstone, as it weathers more readily, and, as it is not as stable a compound, the accessories form new combinations with it to its disadvantage. Limestones should be as free as possible from all cements, excepting silica. Ferruginous cements are worse here than in sandstone, as they react on the stone, and carry to the interior the process of disintegration. Pyritous aggregates have the same effect. Coarse-crystalline silica unfits the stone for careful working, but fine-crystalline silica adds to its strength. The weathered outcrops will allow us to determine the result of time upon a given stone. The *beauty* of a stone is frequently destroyed by such an accessory as the mineral oil in the Niagara limestone in northern Illinois. When quarried, it is white, but soon becomes smutty in cities, while it remains cleaner in the purer air of the country. As the oil is not evenly distributed, the stainings are irregular, and are thought sometimes to add to the appearance of the stone.

Marble. In the language of the trade any stone that is fine-grained and capable of taking a polish is a "marble," so that many ordinary limestones fall under this designation. The true marbles, will however, occupy the greater part of the material sold under the name. For exteriors dense and strong stones are necessary, while loose and soft ones can be used inside. In any case the stone should not be placed

where it will be subjected to strain, or it will crack, if not crush. The modern methods of sawing stone from the solid in the quarry and working the product with the sand-blast allow us to market many brittle stones that formerly could not be used.

Slate. Not all parts of slate deposits are valuable. Slates should split readily and into thin and even plates. All seams and streaks of quartz, calcite, and other accessories should be avoided, as they condemn the product. Contaminations of pyrites, too much calcite as a cementing medium, and too great porosity shorten the life of slate. Weathering takes place mechanically and chemically. The mechanical part is like the straining already noted from changes in temperature, and slates are more subject to this than other stones, owing to their color and exposure to greater amounts of heat. They are further unfortunate in being placed with the bedding exposed to the weather, so that the strain comes along those planes where cleavage is readiest, and the changes from day to night, or from sun to shower, induce great and sudden strains. The chemical weathering is on a parallel with that in limestones, and is due to the decompositions of the accessories and the attempt to form stable compounds at the expense of the rock. Both forms of weathering are going on at the same time, so that in the purest slates mechanical weathering loosens the outer film in minute folia, and these are knocked off by the impact of rain-drops. The slates free from impurities and exposed in the purest air will weather rapidly, but the color of the roof will show whether the weathering is mechanical or chemical. Good slate will show dark after years of exposure, but bleached and mottled slate shows chemical action on too great an amount of cementing medium, or on spots of impurities. Those wishing to study the strength of slates will find Dr. Merriman's discussions

before the American Society of Civil Engineers of great value.

Clays. For brick and coarse constructions all clays are more or less useful, but it may be well to bear in mind that alkalies make clay fusible; and while a small amount may be good, and may render the product denser, too much will make it so fusible that it will warp during firing, or endanger the strength of a structure during a conflagration, where only a part is on fire. Pottery clays are mixtures of kaolin, as the pure mineral shrinks, cracks, and checks, so as to spoil the product. Silica counteracts this. Iron is the most undesirable accessory under any form, as it destroys the white color. Fire-clays are found as the under-clays of the coal-beds, where vegetation has removed the alkalies and alkaline earths. Any accessories that tend to flux the clay must be looked for in the examination of the deposit for this purpose. Segregations of "giant granite" are valuable for the feldspar, which is ground and used as a flux or admixture in the paste. Flints are used after grinding for similar mixtures.

Sands. These are used for glass of varying kinds. Clean sea sand free from iron, or sands from the modified drift of the northern part of the United States, as well as some weathered outcrops of the calciferous sand-rock, are valuable for making ordinary window-glass, but flints are necessary for the whiter and clearer article. For bottles (green) any sand will do, and even granulite is used in abundance, as it contains the necessary ingredients, and can be charged at once into the furnace. It is found in Canada and the eastern part of the United States. Sands for moldings must have sufficient clay to keep the form.

Mortar, Cement. Limestone for mortar should not have more than 8 per cent of silica or similar impurities if first-class mortar is desired. Hydraulic cements are found

along the junctions of slates and limestones, but all such junctions are not "hydraulic." Those that "set" under water are called "cements" when they set without first slaking, but "hydraulic limes" when they slake first. Specimens should be burned and ground to see whether this property is inherent, as without it the deposit is neither limestone nor slate, and of little value.

Abrasives. For grinding and polishing it is necessary to secure something harder than the body to be treated. It is not always necessary to secure the hardest substance. We can divide the abrasives into the hard, medium, and soft varieties. The hard comprise the corundums, which are found in the Archæan formations, and are separated from the matrix by grinding, and removing the iron ores with the magnet. The medium abrasives are ordinary sand (quartz), garnet, and other minerals of similar hardness that are found in sufficient abundance. The soft abrasives are tripoli and infusorial earth. Tripoli is also used as the *dope* in dynamite. As compact abrasives the novaculites of Arkansas are predominant in this country, though gritty mica-schists and metamorphic phyllite are used for coarse hones. The best and finest oil-stone in the world is the microcrystalline garnet rock of Belgium. For millstones gritty sandstones, buhrstones, porous porphyries, etc., are used.

Lubricants. The minerals used for diminishing friction are graphite, talc, and mica. All of them must be free from grit. It has been found that their value lies in the fact that they are foliated, and the best graphite lubricant is now delivered in flakes rather than in powder. Mica is freed from grit and ground to a flaky impalpable sand. In this way the micaceous segregations in "giant granites" can be utilized. In the same way the foliated varieties of talc and graphite are generally freer from impurities than the crystal-

line states, and are more readily and better adapted to the market.

Fertilizers. For this the phosphorites and guano furnish phosphorus, and peat improves the texture and makes the soil warmer. Lime slaked with brine, marl, and gypsum are generally useful, while carnallite and salt are valuable to furnish potash, soda, and chlorine.

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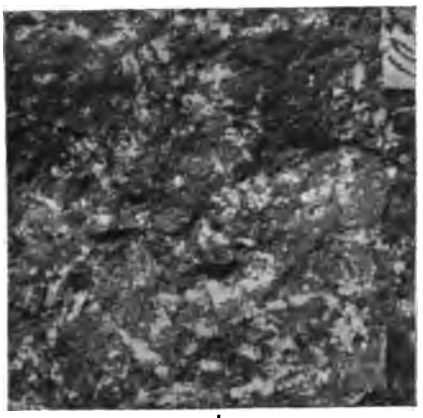

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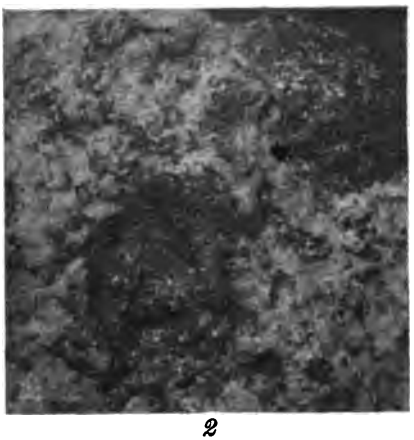

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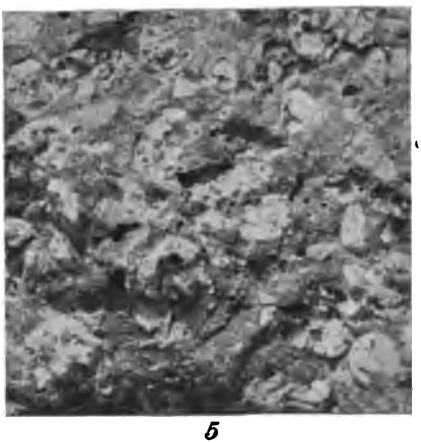

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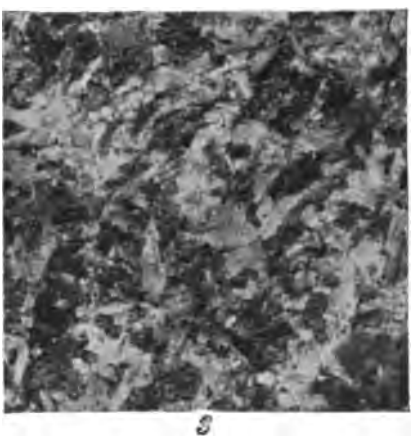

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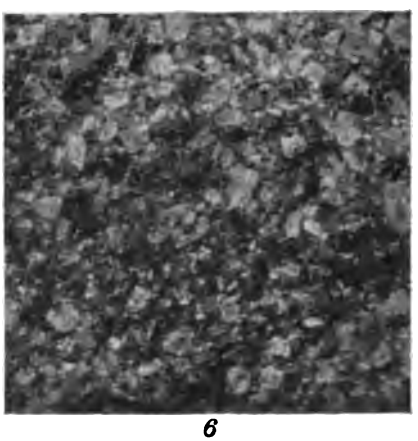

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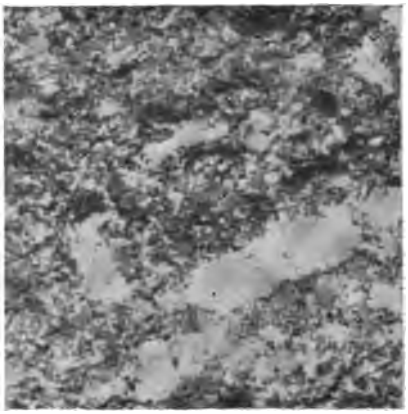

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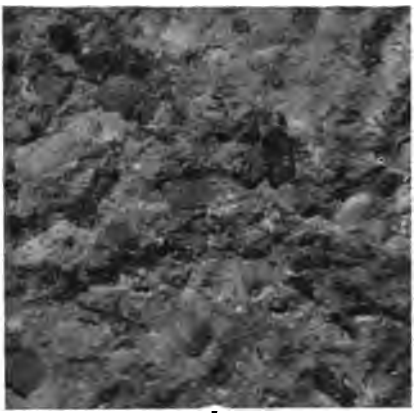

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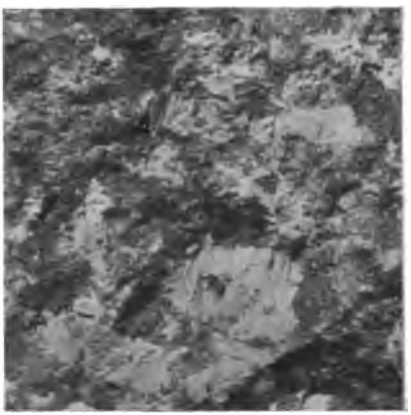

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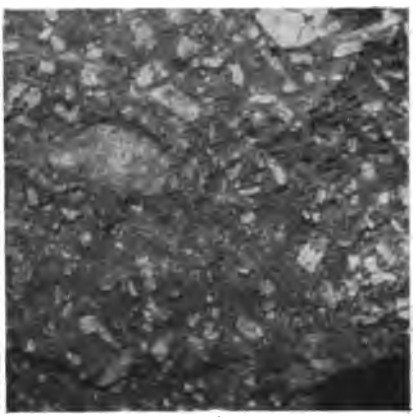

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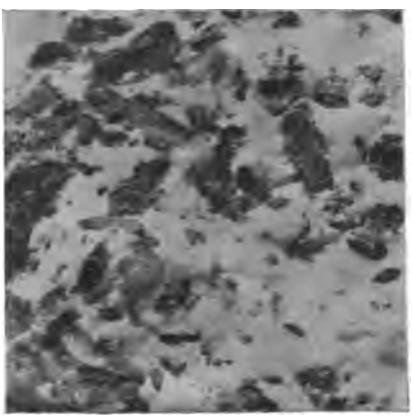

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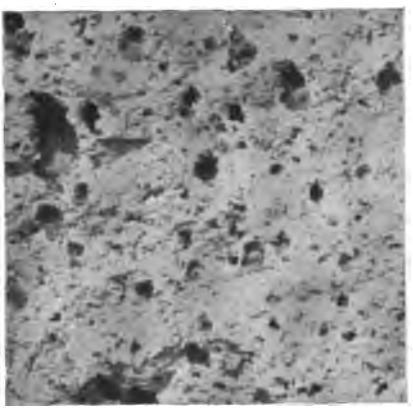

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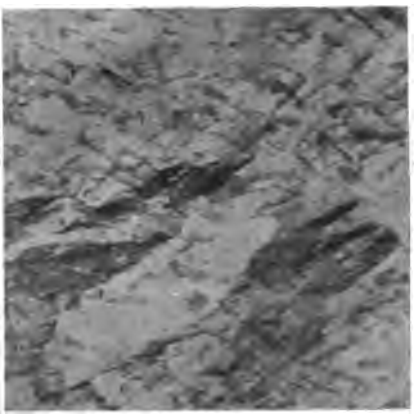

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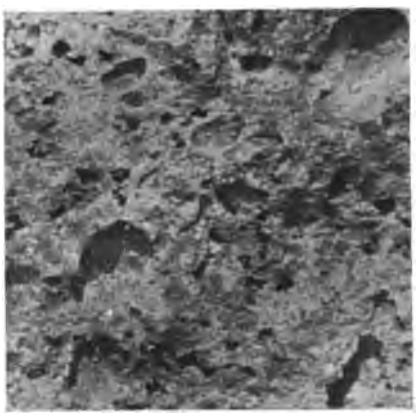

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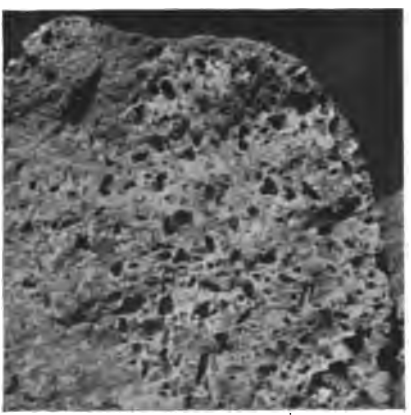

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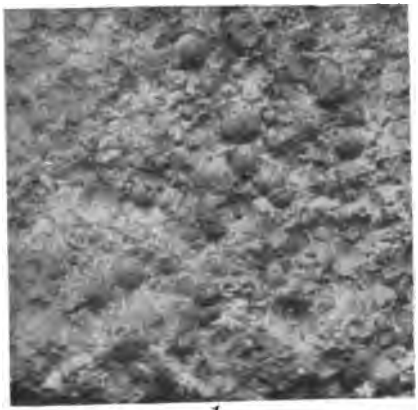

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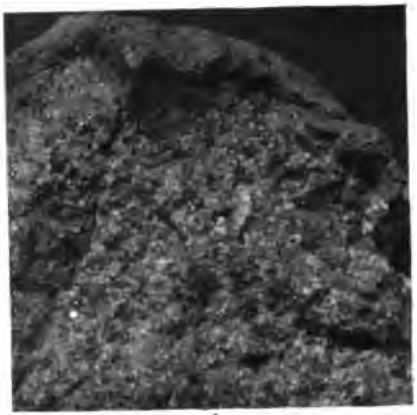

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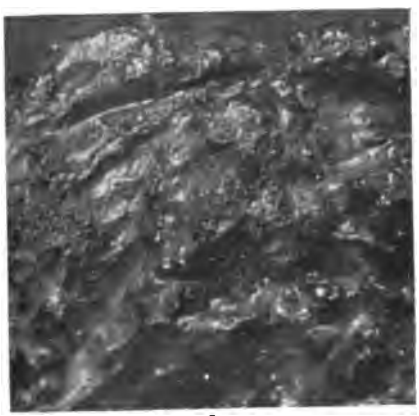

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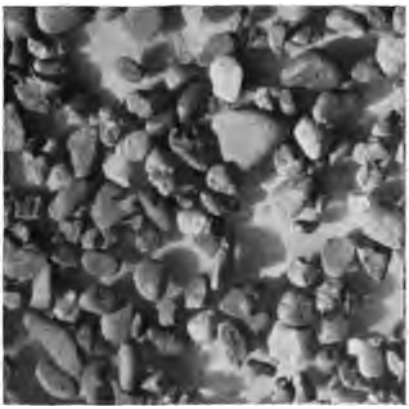

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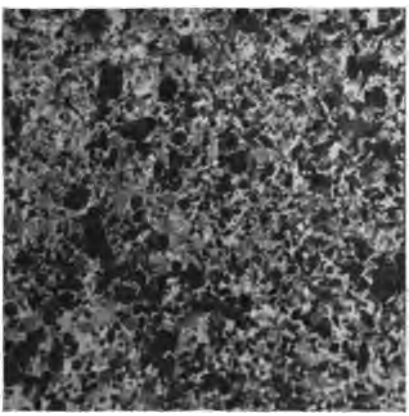

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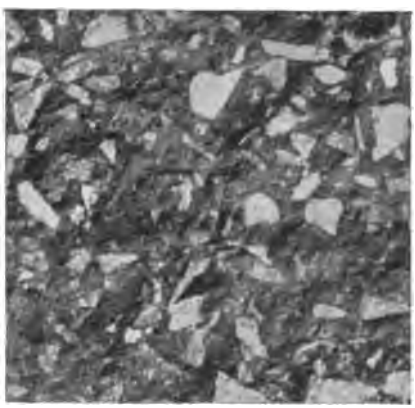

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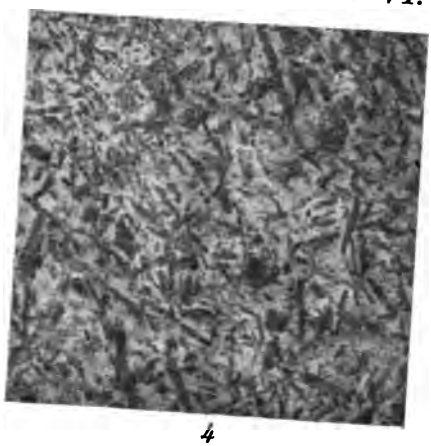

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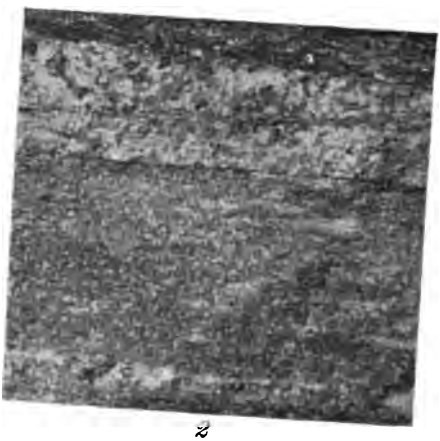

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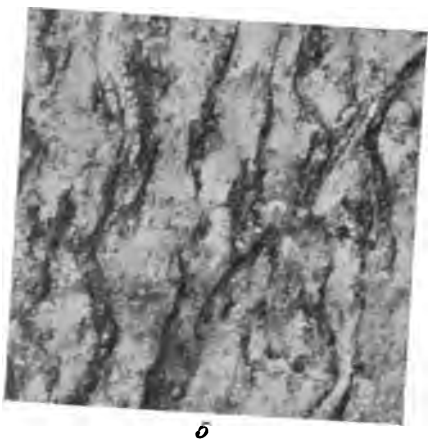

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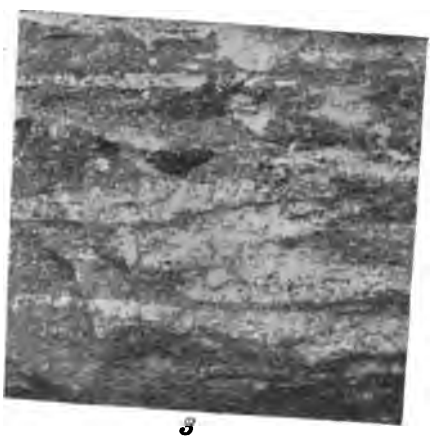

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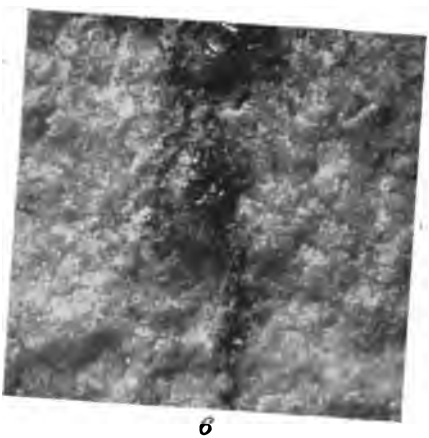

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